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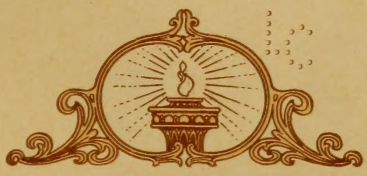

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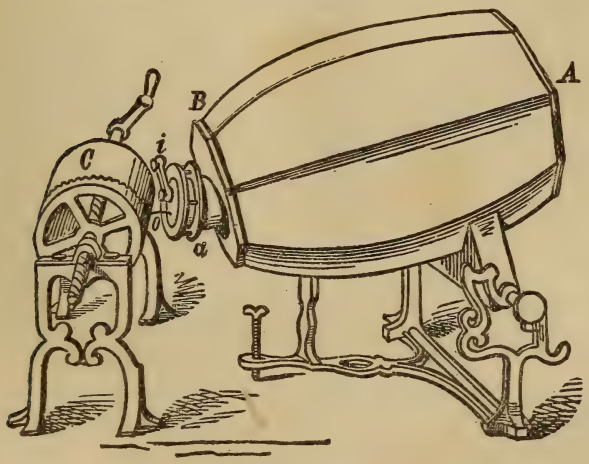
THE STORY OF THE PHONOGRAPH.

By RAY STANNARD BAKER.

THIS is the wonder of the phonograph: it is a machine which makes pictures of sounds, and then, at will, changes these pictures back into sounds again. A picture of a matchless solo by Melba is made in Paris on a little wax cylinder; the cylinder is sent through the mails to New York like any other picture, here to be transformed again into the voice of Melba, repeating all the sweetness and richness of



SCOTT'S PHONAUTOGRAPH.

The First Suggestion of a Talking Machine, in Which the Sound Pictures were scratched on a Cylinder Covered with Lampblack, by Means of a Hog's Bristle.

the original tones. The voice of Nicolini, preserved in pictures, still sings, although the singer himself is dead. And this is something hard to realize, even at this day when the phonograph has become almost as familiar as the sewing-machine.

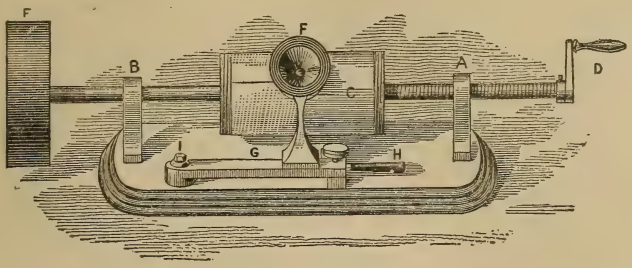
Every man has in his throat a delicate membrane which is set to quivering every time he speaks. The vibrations thus produced in turn set the air to quivering, and these waves roll through space, very much like the waves on the seashore, until they strike on the drum or membrane of the ear. That is the way we hear; it is nature's telephone. If the vibrations are rapid we say that the voice is high; if slow, we say that it is deep. Each note has its own different vibrations.

Away back in 1857 Leon Scott, knowing these simple facts in physics, conceived the idea of making sounds produce pictures. It was an idea as original as it was bold. In the experiments which followed, Scott constructed a curious little device called the Phonautograph, which vividly foreshadowed a part of the operation of the phonograph. It consisted of a thin membrane — a bit of bladder — stretched tightly over a barrel-shaped frame. In the center of this membrane a stiff hog's bristle was firmly fastened. On speaking with the lips close to the outer end of the frame the membrane vibrated in accordance with the sound waves thus produced, the bristle moved back and forth and scratched a continuous wavy track on a revolving cylinder which had been well daubed with lampblack. This wavy line was an actual picture of the human voice. But it was a mere laboratory experiment, and no one even dreamed that such a sound picture could be again transformed into speech — until the idea came to Thomas A. Edison with the suddenness of inspiration.

It was in 1877, long before Edison had become widely famous. At that time his experiments were carried on in a shop in Newark, New Jersey, where he was surrounded with a little company of trusted workmen. It was at the time when Edison often became so absorbed in his schemes for inventions that he forgot his meals, and frequently worked night and day for two or three days together, keeping all of those about him as busy as he was himself. Sometimes he would call in an organ-grinder to keep the men awake and cheerful until the strain was over, and then he would hire a boat and take all hands down the bay with him on a fishing excursion. It was with this singleness of purpose and loyalty that Edison and his men always worked together.

Not long ago I visited Edison's great laboratory at Orange,

New Jersey, where more than seven hundred men are employed in coining the visions of the master's brain. I found Edison himself sitting in one of his characteristic positions, half leaning upon a table filled with drawings, his head on his hand and his fingers thrust through his hair. He told me



Edison's First Phonograph.

briefly how he came to invent the phonograph, and his story was later much extended by John Ott, who was with him through all of the experiments.

The inventor had been working during the early part of the year 1877 in developing and improving the telephone, inventing the transmitter which has since borne his name. This consisted of a disk of carbon, having a sharp-pointed pin on the back of it. He had noticed many times that when he spoke against the face of the disk the vibrations would cause the pin to prick his fingers or to indent any soft substances held near it. This was one fact; he carried it in mind, but it gave him no particular suggestion. It was, indeed, only a step beyond Scott's discovery.

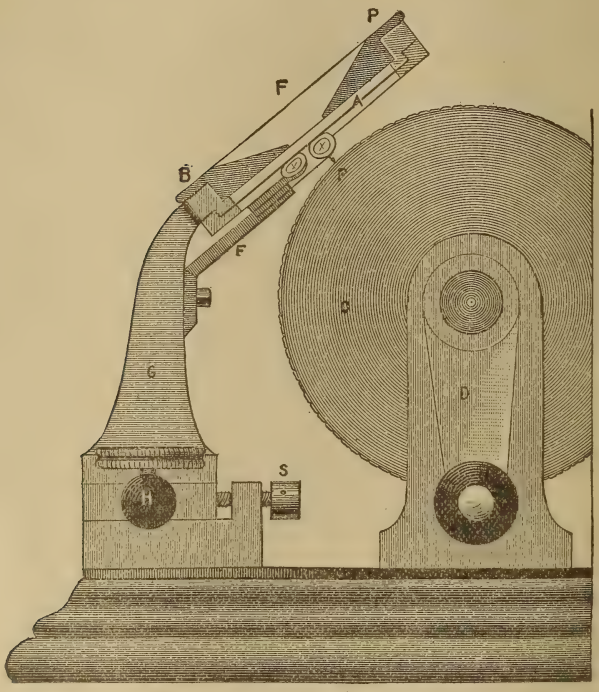
Previous to this time Edison had invented a remarkable device for the automatic repetition of telegraph messages. It consisted of a simple apparatus by means of which the dots and dashes of the original message were recorded in a series of indentations on a long, narrow strip of paper. This record could be fed into a sending machine and the message re-transmitted without the service of an operator. In other words, Edison had made pictures on paper of the sounds communicated over the telegraph wires, thereby approaching the phonograph from another direction.

"In manipulating this machine," Edison wrote in 1888, "I

found that when the cylinder carrying the indented paper was turned with great swiftness it gave off a humming noise from the indentations — a musical, rhythmic sound, resembling that of human talk heard indistinctly."

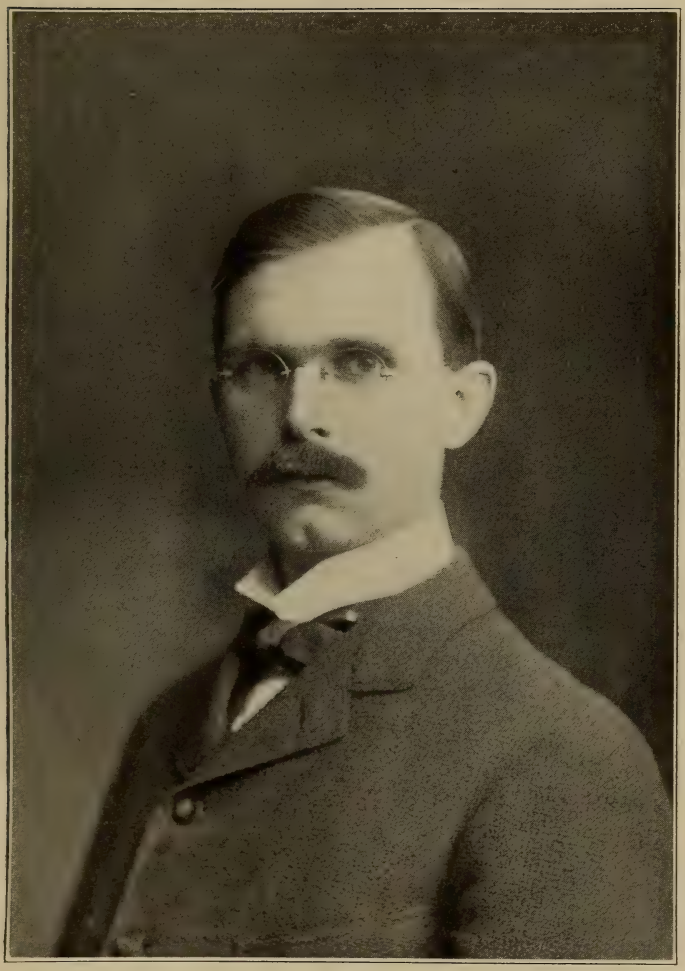
Here was another fact — unconnected as yet, but exceedingly important as pointing to the great discovery.

"I remember," John Ott told me, "that Edison had been working at his bench in the laboratory nearly all day, silent for



Cross Section of Edison's First Phonograph, Showing Method of Operation.

the most part. Quite suddenly he jumped up and said with some excitement: 'By George, I can make a talking machine!' Then he sat down again and drew the designs of his proposed machine on a slip of yellow paper. I don't think it took him above ten minutes altogether."



RAY STANNARD BAKER.

On the margin of that design Edison marked "$8," and handed it to his foreman, John Kruesi.

"My men all worked by the piece in those days," Mr. Edison told me, "and when I wanted a model made I always marked the price on it. In this case it was $8, I remember. Kruesi went to work at it the same day, and I think he had it completed within thirty-six hours. We used to try all sorts of things, and most of them were failures; so that I didn't expect much from the new model, at least at first, although I knew it was correct in principle."

But Kruesi fitted the tin-foil on the cylinder, and brought the machine to Mr. Edison. The inventor turned the handle and spoke into the mouthpiece:

"Mary had a little lamb,
Its fleece was white as snow,
And everywhere that Mary went
The lamb was sure to go."

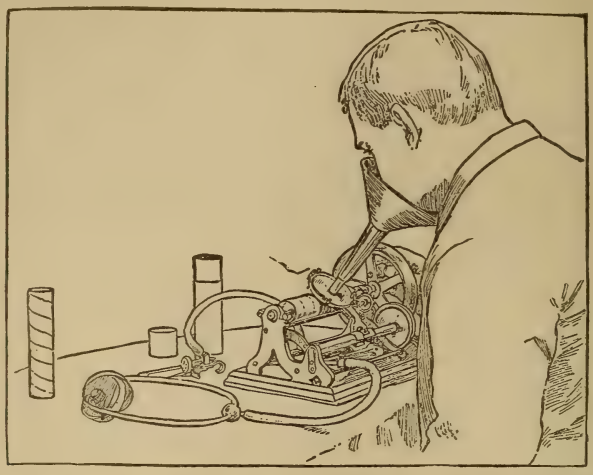
Then he set the recorder back to the starting-place and began to turn the cylinder. At the very best he had not expected to hear more than a burring confusion of sounds, but to his astonishment and awe the machine began to repeat in a curious, metallic, distant voice:

"Mary had a little lamb . . ."

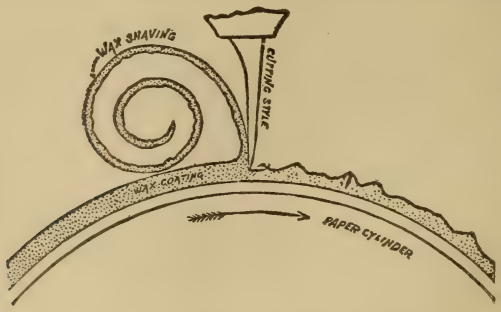
And thus the first words ever spoken by a phonograph were the four simple lines of Mother Goose's melody. The idea had come to the inventor with a flash of inspiration, and the machine had proved its marvelous possibilities on the first trial. Few inventions ever have been conceived and carried to success so swiftly. Kruesi's eight-dollar machine, which could not now be bought for hundreds, is in the patent museum at South Kensington, London.

The first machine, although it talked, was a very crude affair compared with the all but perfect phonographs of to-day. In principle it was exceedingly simple. There was a diaphragm or membrane, having a sharp-pointed pin attached to its under surface. When sound waves, caused by a spoken word or a piece of music, struck this diaphragm, it vibrated, and the pin rose up and down. The cylinder on which the sound pic-

tures or records were to be made was covered with tin-foil. At every vibration of the pin, indentations of various depths were made in this tin-foil. These little holes were so small as to be scarcely visible to the naked eye, but when the dia-



Making a Record on One of the Early Forms of the Graphophone.



Showing How the Record is Engraved on the Wax Cylinder — Much Enlarged.

phragm was set back to the beginning and the cylinder was turned, the pin, traveling up and down over the rough road of indentations, caused the diaphragm to vibrate and give out the same sounds which had been previously spoken into it. A reference to the pictures on pages 3 and 4 will show clearly

just how the machine worked. *A* is the plate or diaphragm, 1-100 of an inch thick, which vibrated when spoken against, driving the point *P* into the cylinder *C*. *F* is the mouthpiece, and *D* the crank by means of which the cylinder was turned.

Few inventions ever awakened a world-wide interest more suddenly than did this of the phonograph. When it was first exhibited in the "Tribune" building in New York, every scientific paper, every magazine, and every newspaper in this and in foreign countries gave accounts of the invention, and dealt with its dizzying possibilities. Edison himself wrote an article for the "North American Review," in which he told of some of the marvelous uses to which the machine would be put in the future.

Edison patented his invention both in the United States and abroad, and manufactured a considerable number of machines, chiefly for use in college laboratories. Then he became deeply interested in a series of experiments with incandescent electric lights, and the phonograph dropped out of his mind for many years.

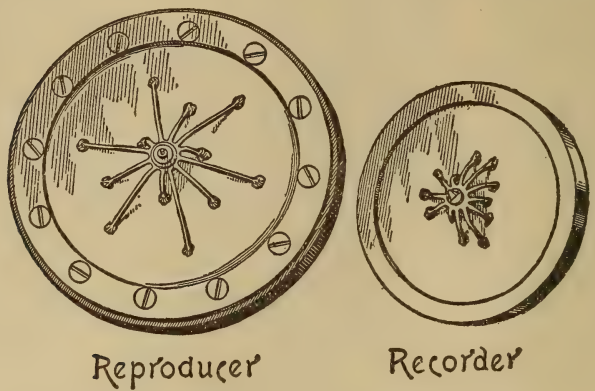
In the meantime Alexander Graham Bell, the inventor of the telephone, had received the most distinguished honor that can come to an inventor — France had bestowed upon him the Volta prize, an honor instituted by Emperor Napoleon the Great. It had been awarded only once before — to Faraday — and it has never been awarded since. With the money portion of the prize, amounting to 50,000 francs, Mr. Bell conceived the idea of forming an association for the advancement of the science of sound. To this association, composed of himself, Dr. Chichester A. Bell, and Charles Sumner Tainter, he gave the name "Volta Laboratory Association." From 1881 to 1885 these three men labored hard upon improvements in the method of recording and reproducing sound, finally producing a machine differing from Mr. Edison's in that it *engraved* the sound pictures on a cylinder of wax instead of *indenting* them on tin-foil, a very great and important change, which enabled them to reproduce speech and music in a wonderfully life-like manner. This machine was called the *graphophone*.

Another machine, the *gramophone*, was invented by Charles Cros, a Frenchman. In this device the record is scratched on

a metal cylinder which has first been daubed with a waxy substance. The cylinder is then taken out and immersed in acid. Where the recording stylus has scratched the wax away there the acid does its work, etching in the solid metal the wavy sound pictures left by the stylus. The sounds are then reproduced as in the other machines.

In later years Mr. Edison and Mr. Bell have made many improvements in the talking machine until it has reached its present perfected state.

Other important additions have been made by Lieutenant G. Bettini. Bettini discovered that all parts of the glass dia-



BETTINI SPIDER DIAPHRAGM ATTACHMENT.
For Making and Reproducing Difficult Records.

phragm used by Mr. Edison did not vibrate equally when spoken against. For instance, the center might vibrate at one speed and the sides at another, thereby producing the peculiar metallic or "tinny" effect which makes many phonograph records disagreeable. Consequently, instead of attaching the recording point directly and firmly to the center of the diaphragm, Bettini used what he called a "spider"—a little frame having several legs, the feet of which rested against the diaphragm at many different points, thereby making the diaphragm sensitive to every variety of sound, even high soprano voices, which have been exceedingly difficult to record. Bettini uses a diaphragm of aluminum instead of glass.

The sound pictures or records of the phonograph are now

engraved on a wax cylinder with a fine stylus, the point of which is a bit of sapphire. After one record is made it can be readily duplicated. The old-fashioned ear tubes are giving way to horns, which bring out the sound more distinctly, and distribute it over a whole room. When one record is worn out — and it can often be used more than a hundred times — the wax is shaved down and the cylinder is ready for another impression. Most of the modern talking machines are operated by clock-work, although some are fitted to run by electrical power, or even by foot-power like a sewing-machine. The prices vary from five dollars well up beyond a hundred dollars.

One of the most interesting things in connection with the phonograph is the new profession of record-making — for a real profession it is. At Mr. Edison's laboratory in Orange, New Jersey, a whole building is devoted to the production of singing cylinders, instrumental music, band music, solo, and speaking cylinders. A curious and wonderful place it is. In one little room shut off from all the others by tight doors I saw a man seated on a tall stool. He was talking and laughing uproariously in Yankee dialect into the flaring end of a long tin tube. At the other end of this tube there was a phonograph with a boy about twelve years old watching the cylinder to see that the stylus was doing its work. The speaker, who had his coat off and was perspiring profusely, would first announce himself: "A humorous sketch, entitled 'Uncle Eben in Fifth Avenue,' by the well-known comedian ———," and then he would begin his talk with no audience but the tin tube and the boy, who looked vastly bored. In another room there were several phonographs placed close together on a shelf, with their horns grouped around a slim young man, who was playing a lively jig on a banjo. Close behind him loomed the back of a piano, upon which a companion was playing an accompaniment. In still another room two men and a woman were singing a church anthem into the receiving horn of a phonograph. Their heads were close together, and both the men had their coats off, it being a hot day. Behind them on a pair of sawhorses stood a piano, which was being played with the utmost unconcern. If I had closed my eyes I certainly should have thought that I was sitting in a church, and that the anthem was coming from the choir loft. When a record is finished it is taken

out and repeated to see if it is correct, and the players or talkers gather around to hear their own words. If the cylinder is a success it is duplicated many times, and placed in the regular library of the phonograph, ready to go out to the users of the machines in different parts of the country.

And yet records of this sort are not always successful. Not every one can make a first-class phonograph record. Some there are whose voices are too soft to make distinct impressions in the wax. The best voice is one that is almost metallic in its timbre — even harsh and hard. For the same reason a cornet makes a far better record than a guitar; a piano, from its sharp and ringing tones, is better than a violin. In this way the phonograph has developed its own especial singers and players. Some soloists and talkers, who have never been able to make a success on the stage, have earned a peculiar and valuable reputation of their own among the users of phonographs. They may be as awkward as they please or as unprepossessing of manner or of face — if only they sing so that their voices come out clearly and beautifully from the little wax cylinders, their fame is made. And some of these singers and players earn very large sums of money. They receive, in general, one dollar for every song they sing or every "piece" they speak, and they often make from twenty to fifty records in a day.

In Mr. Bettini's studio more attention is given to voice records of famous men and women. Here Sarah Bernhardt came and talked into the phonograph, and here Campanari, Ancona, Plançon, and other singers equally famous, have sung. Here, too, you may hear the voice of Mark Twain talking out with beautiful distinctness. Indeed, through this means, a famous man's voice may become as familiar as his picture, and it may go on talking and giving pleasure to the world long after the man himself is dead.

Recently a phonograph with a large-sized cylinder has been constructed for making unusually clear records. This improvement was suggested by Thomas H. McDonald, and one wonders that no one thought of trying it before, since the principle of the improvement is simplicity itself. The surface of the large cylinder moves much more rapidly than the surface of the small cylinder, and the groove cut by the recording stylus is

EDISON IN HIS LABORATORY.

much longer. That is, the stylus, instead of making a series of abrupt holes in the wax, as it does when the cylinder moves slowly, scoops out long hollows with sloping ends. There being no sharp crests or holes in the groove, the reproducing ball follows every gradual ascent and descent, and does not leap from crest to crest, blurring the sound, as in the case of some of the smaller cylinders.

This new style of cylinder has been found to be especially valuable for recording the music of a full brass band or of an orchestra, and some exceedingly fine and popular records of this sort have recently been made. But of all phonograph records, jolly negro and comic songs are the most popular. Next to them come instrumental solos, and after that church chimes, quartettes, and so on. Recently a set of cylinder records have been made to play dance music, and at the same time to call the figures, so that for a small dancing party no regular musicians are needed.

Another very wonderful development of the phonograph which is now in course of evolution is the reproduction of entire operas. Not long ago Mr. Edison had a portion of the opera of "Martha" performed before one of his kinetoscopes; he succeeded in taking 320 feet of pictures. The acting of the opera can now be thrown in lifelike moving pictures on a screen, and at the same time the phonograph may sing the music which goes with each scene, so that together a portion of the opera will be completely reproduced — a marvel which could not have been imagined even ten years ago.

It has been found that the phonograph will "hear" and record sounds too high and too low to reach the human ear. The very deepest tones to which our ears will respond have sixteen vibrations to the second, whereas the phonograph will record down to ten vibrations. And then, more wonderful than all, the pitch can be raised until we hear a reproduction of these low sound waves — until we hear the unhearable.

Within the last few years the phonograph has developed many curious and important uses. It has been employed with success as a teacher of languages. It reproduces perfectly the words and accents of a foreign tongue so that a student may hear the difficult inflection repeated over and over until he learns it, without a living teacher. Indeed, whole lessons,

including the meanings of the various words and any necessary explanations can be talked into the phonograph without the least difficulty. In similar manner the phonograph has been used for teaching small children their lessons, and in one case that I know of a minister actually preaches his sermons first into a phonograph and then sits back and listens to his own words as if he were a member of the congregation, noting the mistakes in delivery, and at the same time committing the sermon to memory. In many scores of business offices the phonograph is used exclusively for purposes of dictation. The machine is frequently placed in a drawer of the desk, so that whenever the business man wishes to dictate a letter he merely opens the drawer, starts the machine, talks as long as he wishes, and then stops the cylinder. In this way he does without the services of a stenographer. At any time during the day the typewriter girl may come and take the record away, place it in her machine, insert the tubes in her ears, and copy the letters which the business man has dictated. In this way both may work without interruption. Several busy men in New York have phonographs in their offices into which visitors who call during their absence may tell of their errands. A phonograph in a restaurant or a barber shop has long been a popular attraction, and I have known of a phonograph being used by a newspaper writer for dictating his articles. Two St. Louis inventors have recently suggested the use of phonographs in place of the whistling buoys on dangerous shoals. One of these inventors says:

"We intend to place one of our phonograph buoys on the noted Kitty Hawk reef at the mouth of the Savannah River. At present a bell buoy marks that dangerous reef, and you know the action of the waves tolls the bell of the buoy. It will doubtless surprise many vessel captains to hear our buoy, with its clear, distinct sound, say, 'I am Kitty Hawk, Kitty Hawk,' and they will hear it farther than they can hear the bell buoy."

Many years ago Mr. Edison suggested the use of phonographs for recording the works of the greatest writers of fiction. He himself dictated a considerable extract of "Nicholas Nickleby" into a phonograph, and he found that six cylinders, twelve inches long and six inches in diameter, would hold the entire

novel. Think what a boon such records would be to a blind man, or, indeed, to a man who comes home with worn-out eyes from a long day's work in the office. The phonograph could talk off the story without a break, and if it had been dictated with expression and spirit, the effect would be that of listening to a good elocutionist.

And thus the phonograph has become a great factor in promoting the pleasure of the race as well as in assisting it with its work. The wonder of the invention — a machine which talks like a man — is yet new enough to make us feel as the famous Emperor Menelek of Abyssinia did when he first heard the phonograph. After the recent victory in the Soudan, Queen Victoria spoke a message of friendship and good-will into a phonograph. The royal words were delivered one Sunday afternoon, the phonograph working perfectly. The Queen's voice was produced with great clearness, and Menelek insisted upon hearing the message repeated many times. First he would listen to it as it came from the trumpet, then he would use the ear tubes. And when it was over he relapsed into silence, and then ordered a royal salute to be fired, while he stood in solemn wonder before the strange machine that talked.

AERIAL NAVIGATION.

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THE problem of human flight is being vigorously attacked, and there seems good reason for hoping that the twentieth century will see its more or less complete solution. The great interest which has been taken in the work of the various men of science and inventors who have lately given their best efforts to the study of flight has made their names familiar as household words throughout the civilized world. Several bodies have been founded for the express purpose of unifying effort in this direction, such as the Aero Club of France, the Aeronautical Institute and the Aero Club in our own country. Under their auspices experiments are being undertaken, and discussions conducted, which have at least the merit of calling public attention to the advances made within the last generation towards the solution of one of the most attractive problems that mechanical science can attack. Three popular books lately published on the subject, though not well written and far from scientific in method, furnish an appropriate opportunity for taking a survey of the history and present position of these advances.

The possible achievement of flight has always been a stimulating prospect for mankind. For thousands of years the hope has been fondly cherished, though only within the hundred and twenty years that have elapsed since the discovery of the balloon has it been translated into practice. The winged horses of the sun, Juno's peacocks, Medea's dragon car, Pegasus, the flying carpet and the ebony horse of the 'Arabian Nights,' bear witness to its widely spread persistence. Aryan mythology is full of tales of flying men, from Dædalus to Peter Wilkins. Anthropologists tell us that the original source of the familiar nightmare, in which most of us have known the exciting and fearful joys of dashing through the air and sailing

down aerial switchbacks, may be a reminiscence of that "probably arboreal" ancestor who frisked and gamboled, with the help of a prehensile tail, among the loftiest boughs of the primeval forest. More probably — for even the youngest of sciences is not infallible — it was derived from an envious watching of the condors and "large birds of prey" which in our own times gave Lilienthal his inspiration. The semi-poetic imagination of the early world working on such material was quite capable of endowing man in fancy with the powers of flight which are attributed by nearly all races to wizards and angels, and which science now promises to confer on the ordinary citizen at no very distant day.

There is not much of practical value to be learnt from the early stories of flight which are to be found in most mythologies, though they are interesting to those who study the anticipation of modern discoveries by the far-reaching mind of untutored humanity. Dædalus was apparently the first man to whom the invention of wings was attributed, and the myth which describes his flight from the prison of Minos, with its unfortunate results for the high-flying Icarus, has been rationalized into a comparatively commonplace tale. As Sir Thomas Browne suggests, "'Twas ground enough to fancy wings unto Dædalus, in that he stole out of a window from Minos, and sailed away with his son Icarus; who, steering his course wisely, escaped, but his son, carrying too high a sail, was drowned." However that may be, one can hardly look for much scientific value in the tale of the wax-fastened wings of the Grecian artist, or in the representation of a winged man, curiously like Lilienthal in his soaring apparatus, which is to be seen on an Egyptian bas-relief, or in the English story of King Bladud's flight over his capital, or the legend of Simon the Magician, or the countless similar tales which represent little more than man's dream that one day he would be able to emulate the birds.

Passing from these mere tales of imagination, however, one finds that the history of human ingenuity records a series of attempts to solve the problem of flight which carry a little more weight. What we have recently learnt from the experiments of Lilienthal, Pilcher and Mr. Chanute, indeed, may incline us to attach more importance to these fragmentary records than students did twenty years ago, before it had been definitely

shown that it is quite possible for a man to fly for hundreds of yards without the aid of any motor-power beyond what is afforded by the action of the wind on properly shaped wings, or (as the modern aeronaut prefers to call them) aeroplanes. The records all agree in asserting one of two things: either that a flying model was constructed which supported itself in the air for some time, or that a man contrived to fly for a short distance, and usually from a high place. We know nowadays that both achievements are perfectly possible without any great mechanical skill being called into play. The first was shown to be feasible at the end of the eighteenth century by Sir George Cayley's little machine constructed of cork and feathers, with a spring of twisted india rubber; and the second in the present generation by Lilienthal, with his soaring apparatus of wood and canvas. Thus there is no inherent impossibility in the story which Aulus Gellius tells about Archytas of Tarentum, that he made a wooden pigeon which flew by the help of a certain "aura spiritus" hidden within it. We need not, indeed, agree with those who see in the last clause a suggestion that Archytas had discovered how to make hydrogen two thousand years before Cavendish, and that his pigeon was really a small balloon, any more than we see it in the mediæval story of St. Rémy about enchanters who rose to the sky "by means of an earthen pot in which a little imp had been enclosed." But it is quite probable that the pigeon of Archytas, like the iron fly of Regiomontanus and other similar inventions of which we read, was an anticipation of the flying model of Sir George Cayley, excogitated from a careful study of the flight of birds. No doubt it is equally possible that, as Mr. Bacon skeptically suggests, the whole thing was a piece of trickery of the kind in which Mr. Maskelyne excels, and that the conjurer's friend — a black silk thread — was the only imp in the machine.

It is more difficult to dispose of the numerous tales of flying men who are to be found in the most diverse parts of ancient and mediæval literature, and which come down almost to the invention of the balloon. Most of these are circumstantially told in a fashion which inclines one to believe that the unscientific chronicler was trying to describe some predecessor of Lilienthal. The evidence for that is at least sufficient to incline us to suspense of judgment. Some of these flying men, in-

deed, were obviously impostors, or at best self-deluders, like the Italian charlatan who (according to Bishop Lesley) undertook to fly from Scotland to France in the reign of James IV. "To that effect," says the good bishop, "he caused make a pair of wings of feathers, which, being fastened upon him, he flew off the castle wall of Stirling, but shortly he fell to the ground and brake his thigh-bone. But the blame thereof be ascribed to this, that there were some hen feathers in the wings, which yearned for and coveted the midden and not the skies." Other tales are less easy to set down as mere figments of the marvel-loving chronicler, or as the tricks of a conscious humbug. Bishop Wilkins, the famous author of "Mathematical Magic," in which the whole question of flying is discussed with great ingenuity, collected various instances of the successful use of wings. "It is related of a certain English monk, called Elmerus, about the Conqueror's time, that he did by such wings fly from a tower about a furlong, and so another from St. Mark's steeple in Venice, another at Norimberg; and Busbequius speaks of a Turk in Constantinople who attempted something this way." A fairly detailed description of this Turk's flight, which took place in the august presence of the Emperor Manuel Comnenus, has been preserved, from which it has been supposed that he actually constructed a simple aeroplane of the kind used by Lilienthal, which would enable him to fly some distance from the top of a tower — tobogganing down the slope of the air, so to speak. It is quite in accordance with what we know of the conditions of such a flight that the Turk lost his balance, turned over and fell to the ground before his flight was completed; if the tale had been a mere invention it would have been easy and natural to make the flight a complete success.

Later stories of the same kind are still more acceptable. In the fifteenth century a certain Gianbattista Dante, of Perugia, is recorded to have flown several times across Lake Trasimene, until one of his wings gave way and he fractured his thigh. In 1678 the "Journal des Savants" records that Besnier de Sablé flew from a height across a river. In 1742 the Marquis de Bacqueville undertook to fly from the top of his house in Paris across the Seine; he actually completed the greater part of the journey — about three hundred yards — but fell on a boat in the river. It is quite permissible to affirm that all these

stories show that men have been for centuries on the verge of the discovery which Lilienthal and his followers have made in our own day, of the possibility of a certain kind of flight — technically known as soaring — with the help of very simple apparatus modeled on the extended wings of the condor or the albatross. Lilienthal's work, of which we shall speak later, does not indeed offer much prospect of our rivaling the birds; but as a contribution to the scientific study of flight it has an importance which should make us think kindly of these mutilated and decried forerunners.

Leaving experiment for theory we find that some of our greatest thinkers have long meditated on the possibility of man's achieving the dominion of the air. A striking page from the notebook of Leonardo da Vinci, which is reproduced in the well-illustrated volume of Messrs. Valentine and Tomlinson, shows that that great artist, who was also a keen engineer, often exercised his mind by devising mechanical wings and flying machines. Roger Bacon actually hit, in a vague and shadowy manner, on the possibility of the balloon. He was led by the analogy of the ocean to conceive that the air might also bear vessels on its surface, and proposed that a large hollow globe of copper or other metal should be wrought extremely thin, filled with "ethereal air of liquid fire," and then launched from some elevated point into the atmosphere, in which it would float. The second and greater Bacon thought that it would be worth while to give much thought to the "experiment of flying," with the birds for guides. When the Royal Society was founded it busied itself (as Addison reminds us) in finding out the art of flying. "The famous Bishop Wilkins was so confident of success in it that he says he does not question but in the next age it will be as usual to hear a man call for his wings when he is going a journey as it is now to call for his boots." Several interesting speculations of this nature are to be found in the pages of Messrs. Valentine and Tomlinson, but they are not of much importance except as showing how earnestly — and often how wildly — men have filled their minds with hopes of flight. We may now turn to modern and practical investigations of the subject, which date back to the invention of the balloon in 1783.

Bishop Wilkins, whose treatises are still a mine of delight,

somewhere classifies the various methods of human flight, with a great air of precision, under four heads:

(1) By spirits or angels.
(2) By the help of fowls.
(3) By wings fastened immediately to the body.
(4) By a flying chariot.

Modern science has rejected the two former methods as beyond the reach of experiment. Even the Society for Psychical Research has not been able to treat cases of "levitation" seriously. The examples of Elijah and Philip and Habakkuk (who was *capable de tout*) throw little light on the subject, and no one would nowadays propose to harness a team of eagles to his balloon, though the late Lord Carlingford actually took steps to patent such a contrivance in 1856, and a similar project is described in one of the recently published letters of Charles Darwin. Modern researches in the art of flying may be classified under Bishop Wilkins' third and fourth heads. On the one hand, we have the experiments of Lilienthal and his followers in the art of soaring by means of wings or aeroplanes fastened directly to the body of the investigator, usually without the addition of any motor-power; these have been directed rather to solving the very important question of balancing a flying machine in the air than to achieving flight in the ordinary sense of the word, and we shall consider them at a later stage. On the other hand, we have the main body of research, which has devoted itself to devising some "flying chariot," or flying machine as we prefer to call it nowadays, in which one or more persons may imitate the way of a bird in the air. Here again we must distinguish two lines of research. The problem may be attacked either by way of aerostation or of aviation, to use the convenient terms which we have borrowed from the French aeronauts for the two chief methods of flight. Aerostation involves the use of flying machines which are lighter than an equal bulk of air, and so float in the atmosphere as a ship floats in water; the modern problem in their case is to discover some means of controlling their flight and driving them independently of the wind. Aviation involves the use of flying machines heavier than air, which are to be kept afloat by the pressure of the air on their surfaces, and which would at once fall to the ground if the motor-power

ceased to act. The ordinary balloon is the type of the aerostat, while a bird or a boy's kite affords precedent for the aviator. For chronological and other reasons it will be convenient to deal first with the problem of aerostation, which appears already to have attained the highest practical development that theoretical reasons suggest as likely.

The central idea of the balloon may be said, as we have seen, to have occurred to Roger Bacon more than six centuries ago. It must have presented itself, one would think, to any thoughtful man who had noticed the clouds floating serenely miles above the earth, or had watched smoke ascending from a fire — at any rate, if we believe the stories about Newton's apple, or the leaping kettle-lid which gave Watt the first notion of his steam-engine. Others after Bacon conceived the same idea, in a still more impracticable fashion. One ingenious gentleman noticed that the dew ascended to the skies when the sun fell upon it, and suggested that egg-shells filled with dew would equally tend to rise. Another proposed to take "the eggs of the larger description of swans, or leather balls well stitched with fine thongs," and fill them with nitre, quicksilver, and other substances "which rarefy by their caloric energy." These people sought, in fact, for a levitational quality akin to the dormitive virtue of opium, but never found it. The Jesuit Lana came nearer to the mark in 1670, when he proposed to raise a flying chariot by means of thin copper globes exhausted of the air, which Torricelli had just proved to have a definite weight. It did not occur to him that the pressure of the atmosphere would instantly crush in such globes if made light enough to have any rising power, and the persistence of error is illustrated by the fact that the use of a vacuum has been seriously suggested in our own day as a substitute for hydrogen.

The balloon might quite well have been invented two thousand years ago, but the first to make any kind of aerostat seems to have been the Italian Tiberio Cavallo, a Fellow of our own Royal Society, who on June 20, 1782, exhibited to his colleagues of that learned body the ascent of soap-bubbles filled with "inflammable air," as the gas which we now call hydrogen was christened by Cavendish when he discovered it in 1760. Cavendish had observed that the extreme lightness of this gas — still the lightest of all known substances — might fit it for such

an experiment, and Black had suggested that a bladder filled with it would rise in the air, though he does not appear to have actually tried the experiment. Thus Cavallo is entitled to remembrance as the pioneer of ballooning. At the same time, however, an idea was germinating in the mind of a French paper-maker which caused the first practical balloon to be of quite a different kind.

In November, 1782, Stephen and Joseph Montgolfier, two young paper-makers of Annonay, hit on the brilliant but simple idea that has immortalized their name. They saw that smoke constantly ascended, and must therefore be lighter than air. They knew vaguely that savants had long been talking of the possibility of making some machine that would rise in the air. Why should not a bag filled with smoke ascend? they asked themselves. They tried the experiment — an apocryphal anecdote declares that Madame Montgolfier's petticoat, conveniently airing by the fire, was the first balloon — and sure enough the bag did rise to the ceiling. Within six months they had constructed a large balloon, with a grate fitted to its neck so as to keep the air inside it rarefied for some time, and the first public ascent — though without an aeronaut — took place, amidst the thunderous plaudits of an admiring crowd, at Annonay on June 5, 1783. The public imagination was immensely taken by this achievement, and it was not long before the daring and ill-fated Pilâtre de Rozier made his first ascent in a balloon of the same kind. Soon it was the fashion to experiment with little fire-balloons, or Montgolfières, and all over France the skies were full of them. The taste rapidly spread to England, where Lunardi made his famous first ascent on September 15, 1784. Readers of Horace Walpole's letters will remember his frequent remarks on the prevalent craze, as he thought it. "Do not wonder," he wrote at the end of 1783, "that we do not entirely attend to things of earth; fashion has ascended to a higher element. All our views are directed to the air. Balloons occupy senators, philosophers, ladies, everybody." Walpole was careful to inform his correspondents that they appeared to him "as childish as the flying kites of schoolboys," though he thought the exploits of the "airgonauts" worth chronicling at some length. He even went so far as to picture a time when our seaports might become de-

serted villages, and all our traffic be conducted through the air. "In those days Old Sarum will again be a town and have houses in it. There will be fights in the air with wind-guns and bows and arrows, and there will be prodigious increase of land for tillage, especially in France, by breaking up all public roads as useless." Within two years after Montgolfier's first ascent, the Abbot of Strawberry convinced himself that "balloonation" was an exploded craze, which could never be of any service to mankind; yet he had a saving doubt, and wrote: "How posterity will laugh at us, one way or other! If half a dozen break their necks, and balloonism is exploded, we shall be called fools for having imagined it could be brought to use; if it should be turned to account, we shall be ridiculed for having doubted."

It is unnecessary here to trace the history of the ordinary balloon, which may be read at length in Mr. Bacon's interesting and popularly written book, and has frequently been told before. We need only remind the reader that Professor Charles, soon after the success of the Montgolfiers, constructed a balloon filled with hydrogen, on the suggestion of Cavallo's soap-bubbles; this made a successful ascent on August 25, 1783. Thenceforward numerous experiments with both kinds of balloons — unchecked by the lamentable accidents which ended the lives of some of the most adventurous aeronauts — soon raised the ordinary balloon to a high degree of completeness; indeed, no serious advance in the art of ballooning has been made since the early days of the nineteenth century, although many details of practical convenience have been brought to greater perfection.

The balloon has done much good service to meteorology, as Mr. Bacon — who is an expert in this matter — points out. It is hardly possible to overrate the importance of the increase in our knowledge of weather and the conditions on which it depends which has thus been brought about. As the late Mr. James Glaisher, whose name is connected with one of the highest and most adventurous ascents on record, expressed it:

"In regard to such matters the balloon is unique, as the atmosphere is the great laboratory of nature, in which are produced all the phenomena of weather, the results of which we perceive on the earth; and no observations made on mountain sides can take the place of those

made in the balloon, as what is required is the knowledge of the state of the upper atmosphere itself, free from the disturbing effects of the contiguity of the land."

It has well been said that the human race spends its days in crawling about the bed of the great ocean of air, on whose movements and fluctuations our weather, with all its economical and social consequences, depends. In studying these fluctuations we are handicapped much as an intelligent kraken would be, if from its immemorial bed in the Atlantic ooze it attempted to construct a map of the surface currents. We profit by the use of balloons as the kraken would profit by the employment of a mobile squadron of sharks and dolphins to report on the movements of the upper waters. Thus we are able to study the meteorology of the atmosphere in three dimensions instead of in two. Of recent years a still further step has been taken in this direction by the employment of small sounding balloons — *ballons sondes* — which are sent up without any human aeronaut on board, charged with a cargo of light self-recording instruments. At the Paris Congress of Meteorologists in 1900 an international agreement was made for the systematic exploration of the upper air by the monthly dispatch of such balloons from meteorological stations in most of the countries of the world. Great Britain, unfortunately, still takes no official part in this work, as we understand, although some contribution is made to it by private enterprise. The balloons are sent aloft on the same day in each month, and when they come down after a flight of many hours they are returned to the place from which they started by the person who picks them up. A few are lost, but most of them find their way back with the valuable message that they bring from the upper regions of the atmosphere. This is by far the most important use that has ever been made or is ever likely to be made of the ordinary balloon, which will hardly be superseded for such a purpose.

The balloon, however, has been a great disappointment to those who hoped that it would solve the problem of human flight. By flight, of course, we mean locomotion through the air — not mere helpless drifting, but the power to go from place to place with the same certainty as our automobiles

possess on the road or our ships on the trackless ocean. The ordinary balloon is quite useless in that respect — as useless as a raft without sail or paddle would be to the transatlantic voyager. It is bound to arrive somewhere, indeed, but no aeronaut can have much certainty within a few scores of miles where he will descend. The balloon, in short, is absolutely at the mercy of the wind. It is part and parcel of the stratum of air in which it floats, and is obliged to go whithersoever that air is journeying. The aeronaut's control of it is solely exercised in the vertical. He can ascend by throwing out ballast, or descend by losing gas — a wasteful process, which shortens the life of a balloon every time that it is employed, and for which many substitutes that should not fritter away these vital necessaries have been suggested, without much success. All that the aeronaut can do to influence the direction of his flight is to choose an air-current which sets approximately towards the place which he desires to reach. As the upper and lower currents often differ widely in direction — clouds may thus be seen apparently traveling against the wind which is blowing on the surface of the earth — it is possible sometimes to find a suitable one by going up or down, but it is clear that such a control is very haphazard and impracticable for the purposes of the traveler. No one succeeded in bringing a balloon into besieged Paris, for instance, though to do so would have earned almost any reward that the aeronaut liked to ask. The failure of Andrée's attempt to make a comparatively short journey is a typical instance of the uncertainty of balloon voyages.

It follows that, from the earliest days of ballooning, men have tried to devise means of controlling the horizontal as well as the vertical motion of the aerostat. At first the prospect seemed extremely alluring, and it was thought that success was near at hand. Men held that the balloon was, so to speak, the hull of a ship, and that it must be an easy matter to equip it with sails or paddles that would enable it to travel as certainly and as fast as the East Indiaman or the Chinese tea-clipper. More than a century has passed away, the agency of steam and other engines has been brought to bear on the subject, but in spite of the ingenuity and pluck of experimenters like MM. Renard and Krebs, or M. Santos-Dumont, there

seems good reason to believe that men were on a wrong tack in looking to any modification of the balloon as the air-ship of the future. For reasons that are now to be set out, it seems probable that we shall have to give up the balloon and return to the older plan of those who endeavored to produce — or at least to imagine — flying machines modeled on the bird.

Very shortly after the balloon was invented, men began to equip it with wings, sails, and paddles, by which to guide it independently of the wind, as a ship or a galley is guided on the sea. The inutility of all such attempts soon made itself practically apparent, and is clear from theory. The ship is able to sail in a direction different from that of the air-current which provides its motor-power because its hull is immersed in a denser medium, which prevents it from driving at the same speed as the wind. But the balloon is all sail, so to speak: it is totally immersed in the air, and must obviously drive along at the same speed as the wind. Thus the aeronaut seems to himself to be always in a dead calm, even if he is traveling thirty miles an hour in a stiff gale. His vessel partakes of the motion of the air in which it floats, and no arrangement of sails will enable him to tack, any more than the rudder will affect a becalmed ship, or a boat drifting with the current of a river. This was soon discovered by experience. Applying the marine analogy, the aeronaut then attempted to give his balloon steerage way by the use of oars or paddles. The principle was correct enough, but we know — as was soon discovered — that no human muscles could thus affect the motion of a huge bulk like a balloon to any extent worth considering. And down to the present time the ordinary balloon is admitted to be incapable of further guidance than the aeronaut can give it by hunting for a more or less favorable current of air.

With the invention of the steam-engine, however, which set its mark so deeply on the whole of the nineteenth century, new hopes arose in the mind of the aeronaut. If steam could drive a ship through the water, he thought, why should it not urge a balloon through the air? Here the marine analogy held good, subject to the limitations involved by the greater tenuity of the medium in which the balloon floats, and on which its screw or paddles have to act. It seemed as if Erasmus Dar-

win's prophecy would be realized — as if the new unconquered force of steam would soon

> "On wide-waving wings expanded bear
> The flying chariot through the field of air."

The combination of the balloon and the steam-engine was quite comparable to the ocean steamer. But in practice these hopes were again doomed to disappointment, and the navigable or dirigible balloon, in spite of the moderate success which has been achieved during the last twenty years by one or two experimenters, is never likely to be of much importance, except perhaps for the limited purposes of warfare or sport. A brief summary of what has been done in this way will lead to a clear perception of the reasons for this pessimistic conclusion.

The first serious attempt to build a navigable balloon was that of Henry Giffard — the distinguished French engineer to whom we owe the well-known Giffard injector — in 1852. It was already clear that the ordinary spherical balloon was ill-adapted to the purposes of aerial navigation, where the resistance of the air is the great difficulty, and Giffard gave his balloon the elongated cigar-shape which has been adopted by almost all who have followed in his footsteps. It was about 100 feet long and 39 feet in diameter, and was driven by a screw actuated by a small steam-engine. In a dead calm this balloon attained a speed of about eight miles an hour, but it hardly passed beyond the experimental stage. The next navigable balloon was also constructed in France, the special home of this type of air-ship: Dupuy de Lôme built it towards the end of the siege of Paris, with a view to using it for the attack of the Prussian lines, but it was not completed until a year later. Its screw was driven by the manual force of eight men, while it attained a speed of about six miles an hour, and readily obeyed its helm in still weather. But, of course, it was quite unable to contend with even a gentle breeze.

The only valid test of a satisfactory navigable balloon is that it should be able to make a trip on an ordinary day and return to the place from which it started. The first to do that — and, with the exception of M. Santos-Dumont's balloon, the only one which has ever succeeded in it — was the balloon "La France," built in 1884 by MM. Renard and Krebs at the French military

aeronautical station at Meudon. This was a fish-shaped balloon, about 165 feet long and 27.5 feet in diameter. It was driven by a screw 23 feet in diameter, made of wood covered with silk, and an electro-motor of 8.5 horse-power, weighing about 1,386 pounds, or 163 pounds to the horse-power — a great contrast to the modern motors used by aeronauts, which weigh as little as 7 pounds or 8 pounds to the horse-power. In the summer of 1884 this balloon made seven successful voyages, attaining a speed of ten miles an hour, and returning on several occasions to the very point from which it set out, after a journey of some miles, part of which was made in the teeth of the wind. For a moment it was thought that the problem was solved. Cool reflection showed — to none more clearly than to the clear-sighted inventors — that this was not the case. The achievements of "La France" — which, though they were much less advertised and are now forgotten by all but students of aeronautics, were fully as remarkable as those by which M. Santos-Dumont has made so great a reputation — seem to have convinced MM. Renard and Krebs that the problem was insoluble with the means at their disposal.

What do we ask of a navigable balloon in order that it may be of practical use? Clearly the first requisite is that it should be able to undertake a journey in any direction, and complete it within a reasonable time. The analogy is that of the ocean steamer, which leaves Liverpool on a given day and arrives at New York on a fixed day thereafter. We can excuse its being delayed a few hours — say even ten per cent. of its schedule time — by bad weather, and we can understand that once in a way an accident to the machinery may prevent its arriving at all. But it would be a quite useless vessel if it had to wait for a fine day to start, and was always liable to be forced back to its original port by a head-wind, or to be driven down to the African coast by a persistent north-wester. An air-ship, to fulfil the same conditions, must be capable of traveling against any reasonable wind. But a balloon is in a worse case than the ship contending with a head-wind, because there is no water for its hull to rest in, but it is totally immersed in the air, and must consequently travel at the same rate as the wind. In other words, if the wind is moving at twenty miles an hour, and the navigable balloon is to travel at twenty miles an hour

in the opposite direction, it must move relatively to the air at a speed of forty miles an hour — that is, it must be capable of making forty miles an hour in a dead calm. Now a wind of twenty miles an hour is nothing out of the way: it is the limit, according to a useful table given by Mr. Walker, of what is defined as a "strong breeze." In order to make head against a gale of forty miles an hour, the balloon must be endowed with a potential speed in still air of fifty or sixty miles, equal to that of our fastest express trains. Now, the resistance of the air varies as the cube of the speed of a moving body, so that, in order to travel at forty miles an hour, which is clearly the lowest speed with which a practical air-ship can be endowed (for the anemometers on the Eiffel Tower have shown that the average speed of the wind at that moderate altitude is eighteen miles an hour), a balloon like "La France" would have needed engines, not four, but sixty-four, times as powerful—*i.e.*, of at least 544 horse-power. Even with the light motors of to-day, such an engine would weigh at least two tons, and to think of fitting it to a balloon is enough to show us the hopelessness of the business. Captain Renard and his colleague twenty years ago retired from the contest, although it is understood that they have since been engaged upon the task of fitting their vessel for use in war, where it might play a very decisive part. Military reasons have kept the work so secret that nothing is really known as to its results.

There is another argument against the likelihood of navigable balloons ever becoming serious rivals to ships and railway trains, which has been expressed with special force by M. P. Banet-Rivet. We have shown that a dirigible balloon, in order to be of any use for the ordinary purposes of travel, or for the conveyance of mails and other light swift freight, must be capable of a speed of at least fifty miles an hour in still air. But what will be the condition of a balloon, made of any conceivable fabric, traveling at such a speed? Anyone who has been on a motor-car doing forty or fifty miles for a short spurt, or will put his head out of window the next time he is in a fast express, will be able faintly to realize the pressure of the air at such speeds. Further, we know that a captive balloon in a gale blowing at anything over thirty miles an hour is liable to be rapidly destroyed. It is simply inconceivable that a bal-

loon of any known material should be able to stand traveling through the air at such a rate. Even if the fabric were capable of resisting the tremendous pressure of the air, it would certainly lose its shape, and be crushed or pitted in front to an extent which would totally impede its progress, if it did not destroy the whole machine. It is clear that only a metallic hull like that of a ship could endure the strain. In that case we are driven to conclude that the navigable balloon which is adapted for really useful speeds must either be so gigantic in size as to be impossible to handle — otherwise it could not raise its own weight — or must be heavier than air, in which case it ceases to be a balloon, and comes into the second class of air-ships, which we have yet to consider, and with which the future of aerial navigation must lie.

If this argument is sound, as it appears to be, it is needless to enter into a lengthy discussion of the most recent attempts to build navigable balloons. The most notable of these, which we owe to the skill and perseverance of M. Santos-Dumont, helps to illustrate our thesis. M. Santos-Dumont has the advantage of using motors whose power in relation to their weight is tenfold superior to anything known twenty years ago, and yet he has not outdone the achievements of "La France." On his most famous trip, when he won the Deutsch prize by flying round the Eiffel Tower from St. Cloud, he only just managed to cover five miles within the stipulated half-hour, and until he is able to show a greatly superior speed to that it is useless to look for any practical results from his work. At the same time, one would not appear regardless of the courage and ability which he has shown in his work, and which have justly earned him a high reputation among those who seek the dominion of the air.

We must conclude that, so far as theory based on existing experience can tell us, the navigable balloon is an unrealizable dream. That is to say, it can never hope to compete with the steamer or the railway as a conveyance for passengers or mails, while no one supposed that it would ever furnish a practical method of conveying freight. Its use must be confined to the purposes of sport and war. In a future campaign it is quite possible that balloons of the type of that of M. Santos-Dumont may play a considerable part. As a method of reconnaissance,

nothing can be more promising than a trip in such a vehicle across the lines of an enemy, while it is conceivable that it might also be used with advantage to keep up communications between a besieged town or fortress and the surrounding country — though that is not very likely. As an actual engine of warfare — dropping high explosives into a hostile army or fortress — it is less likely to be of importance, even if the rule of the Hague Conference, which forbids such a method of fighting, were to become a dead letter, as it probably would if it were found to hamper one of the combatants in a great European war. The practical difficulties, not to speak of the danger to the aeronaut, who would almost certainly upset when he cut loose his load of mélinite, may be trusted to keep this new horror out of the field for a long time to come.

Although we do not believe that the future of aerial navigation lies with the navigable balloon, there is this justification for its discussion at length — that at present it is the only airship which has actually been used by mankind. With the exception of a few sporadic and doubtful cases, no one has ventured to trust himself to the mercy of the flying machine, which supports itself solely by its motion, like a bird. Yet there are various promising experiments to be recorded, and at least one model — the aerodrome of Professor S. P. Langley — has actually flown for half a mile at a time without accident, while Sir Hiram Maxim is convinced, and has convinced those best able to judge, that his full-sized aeroplane is perfectly able to fly, when the still insuperable troubles of balancing in the air and of alighting without destruction are overcome. It remains to consider what has been done in this line, and what are the conditions of the problem.

The analogy of nature shows us that the problem of flight can be completely solved without the introduction of the balloon. Birds and insects, which have solved it so perfectly, are all heavier than the air which they displace, and keep themselves up by the pressure which their wings exert upon it — either by flapping, which is comparable to treading water in swimming, or by soaring, which is the method that the successful flying machine will probably adopt. These processes both depend on the axiom which has thus been enunciated, "The air is a solid if you hit it hard enough." Professor Lang-

ley, in his admirable little essay on the pterodactyl, "The Greatest Flying Creature," points out the distinction between birds like the pigeon or the wild goose, which fly by flapping their wings, and birds like the condor or the eagle, which soar apparently without effort. Elsewhere, in the classic monographs on "Experiments in Aerodynamics," and "The Internal Work of the Wind," to which we owe our most important knowledge of this subject, he has shown all future investigators how to attack the problem of flight. Instead of dealing with the history of flying machines which are related to have flown, from the pigeon of Archytas to the somewhat mythical artificial albatross of Le Bris, it will be more useful to give some account of Professor Langley's results, which he has utilized in the construction of the most efficient flying model that has yet been seen.

In the first place it must be noted that the laws of flight are to be discovered in the behavior of the soaring birds. For thousands of years they have completely mastered the art which man hopes one day to apply to the construction of a flying machine. Darwin's admirable description of the condors which he saw in South America is worth quoting, as an exact observer's account of the process:

"Except when rising from the ground, I do not recollect ever having seen one of these birds flap its wings. Near Lima, I watched several for nearly half an hour, without once taking off my eyes; they moved in large curves, sweeping in circles, descending and ascending without giving a single flap. As they glided close over my head, I intently watched from an oblique position the outlines of the separate and great terminal feathers of each wing, and these separate feathers, if there had been the least vibratory movement, would have appeared, as if blended together; but they were seen distinct against the blue sky. The head and neck were moved frequently, and apparently with force, and the extended wings seemed to form the fulcrum on which the movements of the neck, body, and tail acted. If the bird wished to descend, the wings were for a moment collapsed; and when again expanded, with an altered inclination, the momentum gained by the rapid descent seemed to urge the bird upwards with the even and steady movement of a paper kite. In the case of any bird soaring, its motion must be sufficiently rapid so that the action of the inclined surfaces of its body on the atmosphere may counterbalance its gravity. The force to keep up the momentum of a body moving in a horizontal plane in the air (in which there is so little friction) cannot be great, and this force is all that is wanted."

The problem is to devise a mechanical apparatus which will imitate the condor, and will incidentally be large enough to support one or more human beings who may control its flight. In order to do this it is clearly necessary to understand exactly how the bird supports itself and soars with so little apparent expenditure of energy. Of all those who have set their wits to tackle this problem — some with a certain measure of practical success, if the stories of artificial birds are to be accepted — Professor Langley was the first to carry out a truly scientific investigation. Of the two monographs already mentioned, the one that was published second is really the first to be studied. It deals with the "internal work" of the wind, and has revealed a state of things which no one had previously guessed. We think of the wind as a fairly uniform force; but Professor Langley has shown that, even when it seems steadiest, it is but a generic name for a series of infinitely complex phenomena. It is always variable and irregular in its movements beyond anything which could be anticipated. Even the smallest portion of an air current which can be examined proves to have no homogeneous parts. It consists of an exceedingly complex tangle of tiny and diverse currents. It is by a kind of selective action upon these currents that the bird soars, by choosing out all the variations which happen to suit its motion. The birds "see the wind," so to say, or in some mysterious way recognize a fact which only the happy accident of using a very small and sensitive anemometer revealed to Professor Langley. The stronger and more apparently uniform the wind is, the greater are its relative fluctuations. "In a high wind the air moves in a tumultuous mass, the velocity being at one moment, perhaps, forty miles an hour, then diminishing to an almost instantaneous calm, and then resuming." It is to these minute and rapid changes that Professor Langley refers when he speaks of the "internal work" of the wind. He has lucidly shown how, if we assume, as we must, that birds have an instinctive ability to utilize these fluctuations, they account for such a remarkable phenomenon as the fact that a turkey buzzard has been seen to hover, with no apparent effort, stationary in the teeth of a gale blowing at thirty-five miles an hour.

The application of this remarkable discovery lies in the proposition that it should be possible to cause any suitably dis-

posed body, animate or inanimate, wholly immersed in the wind, and wholly free to move, to advance against the general direction of the wind as a whole. This would be clearly impossible if the wind were so nearly homogeneous as the misleading voice of our senses causes us to suppose. "A ship is free to go against a head-wind by the force of that wind, owing to the fact that it is partly immersed in the water, which acts on the keel; but it is here asserted that — contrary to usual opinion, and in opposition to what may at first seem the teaching of physical science — it is not impossible that a heavy and nearly inert body, wholly immersed in the air, can be made to do this." That is to say, it may be possible to construct a flying machine, whether with an automatic "brain" analogous to the balance-chamber in a Whitehead torpedo, or under the control of a trained aeronaut, which will fly without the use of a motor by utilizing all the favorable variations in the wind, or at least will use its motor as the auxiliary screw of a sailing yacht, for progress in calms or against a persistently unhelpful air current. It may still take many years of experiment and sedulous aping of nature to devise the intricate machinery of the automatic brain, indeed, or to endow human aeronauts with the capacity of "seeing the wind," and constantly shifting the aeroplanes to take advantage of its shifts, which the bird has instinctively acquired in so many ages; but Professor Langley has demonstrated the theoretical possibility of such a machine.

He was anticipated in practice by the ingenious and resourceful Otto Lilienthal, whose sad death by an accident to his wings in 1896 was a great blow to the study of flight, although his work was taken up in the United States by Mr. Chanute and his friends, and there carried to a higher pitch of development. Lilienthal, who was born in 1848, took a very early interest in the problem of flight, and soon perceived that it could best be attacked by a careful investigation of the conditions which determine the soaring of birds. He published the result of his observations in his epoch-making treatise of 1889 on "That Flight of Birds as the Basis of the Art of Flying." In this work he reached independently the result which Professor Langley attained by his study of the wind, and showed that a man equipped with sustaining aeroplanes could "per-

form soaring or sailing flight" without the use of any motor beyond that afforded by the wind itself. He laid down thirty rules for the construction of wings, as his supporting aeroplanes may fitly be called, of which the most important may thus be summarized: —

(1) The construction of flying machines is not dependent upon motors.

(2) Hovering flight, however, is impossible without a motor of at least 1.5 horse-power.

(3) A man has sufficient muscular power to fly in an average wind.

(4) In a wind moving faster than twenty-two miles an hour a man can perform soaring or sailing flight by means of adequate and appropriate sustaining surfaces.

(5) All such flying apparatus must be modeled on the wings of large birds.

In 1891 Lilienthal constructed his first soaring machine, and began to make short flights. With the aid of a bird-shaped framework, so constructed that the inclination of the wings and tail could be altered at pleasure by the athletic experimenter — Lilienthal was a trained gymnast — he successfully attempted toboggan-like glides down an inclined plane of air, starting from the top of a low mound, down whose sides he ran until the air-pressure on the under sides of his wings raised him from the ground. Long and assiduous practice, varied by many tumbles, taught him to steer himself in the air by adjusting the wings to every change in the wind. At length he came to fly as much as a quarter of a mile at a time. The sensation was wildly exhilarating, as Mr. Chanute and other experimenters agree. "Finally," wrote Lilienthal, "we become perfectly at ease, even when soaring high in the air, while the indescribably beautiful and gentle gliding over the long sunny slopes rekindles our ardor at every trial. It does not take very long before it is quite a matter of indifference whether we are gliding along two or twenty yards above the ground; we feel how safely the air is carrying us, even though we see diminutive men looking up at us in astonishment. Soon we pass over ravines as high as houses, and sail for several hundred yards through the air without any danger, parrying the force of the wind at every movement."

Lilienthal insisted, very wisely, on the need for exhaustive experiments of this kind before any attempt was made to build a more ambitious flying machine. The great difficulty with all such machines is to preserve the balance in the air. It is analogous to the difficulty which would be found in riding a bicycle over a surface which was constantly in motion, like the waves of the sea; at every instant the wind is varying and threatening to upset the experimenter, whose aeroplanes then cease to support him and he comes down like a shot pheasant. Lilienthal himself paid the penalty of his boldness with his life; after five years of experiments, he went out one day with a new apparatus which a sudden change in the wind dashed to the ground from a height of about one hundred feet, and he was killed on the spot. His only English follower, Mr. Pilcher, was similarly killed in 1899 by the failure of an essential part of his apparatus. But Mr. Chanute, who discovered that the soaring apparatus might be made much safer by the superposition of several aeroplanes one above the other, believes that he has eliminated this source of danger, and declares that "any young and active man can become expert in a week" with his wings. There can be no doubt that much light will be thrown on the problem of flying by the extended use of such soaring machines. Lilienthal hoped to see "Fliegesport," as he called his art, become a rival to rowing or cycling among athletic lads. "If," he said, "we can succeed in enticing to the hill the young men who to-day make use of the bicycle or the boat to strengthen their nerve and muscle, so that, borne by their wings, they may glide through the air, we shall then have directed the development of human flight into a course which leads towards perfection."

The flying machine of the future, however, will be closer akin to a steamship than to a bird. The purposes of the condor or the eagle are efficiently served by wings which enable them to make wide circles in the air rather than to take long journeys, though for the latter purpose they possess an auxiliary motor in the highly developed muscles of their breasts. But the human flying machine will be used chiefly, if not entirely, for the purposes of the traveler. It must, therefore, be provided with a motor which will drive it rapidly through the air and will render it largely independent of the wind. We have al-

ready seen that the successful machine of this type must be heavier than the air: as Sir Hiram Maxim has said, "it is quite as impossible to propel a balloon with any considerable degree of velocity through the air as it is for a jelly-fish to travel through the water at a high rate of speed." Thus the flying machine must keep itself afloat as well as travel by means of its motor power. That this is possible is clear from the instance of the kite, which is kept afloat by the air-pressure on its under surface; relatively to the air, a kite is moving at a high speed, although it may be stationary with reference to the ground. Here again the classical investigation is that of Professor Langley, who published its results in his "Experiments in Aerodynamics" (1891). He constructed what he called a "whirling table," consisting of a long horizontal arm which could be rotated at any desired speed, so that the behavior of an aeroplane suspended at its outer end could be scientifically examined. By means of a series of most ingenious experiments, he was able to show what conditions the flying machine must fulfil, and what difficulties it has to contend with. In the first place, he discovered that a horizontal plane in motion through the air loses part of its weight, and so tends to fall more slowly than it would do at rest, the difference representing the part which is borne up by the air. If, instead of being horizontal, the plane is inclined at an angle to the ground, it is obvious that the weight thus borne up will be increased; every schoolboy who has ever thrown a paper dart has an empirical knowledge of that fact. But no one had realized the true state of the case, which is expressed in what will henceforward be known as Langley's Law, the fundamental proposition on which the construction of flying machines must be based. This law tells us that the faster a flying machine travels, the less energy will be needed to keep it afloat. In the words of its discoverer: "If, in such aerial motion, there be given a place of fixed size and weight, inclined at such an angle and moved forward at such a speed that it shall be sustained in horizontal flight, then the more rapid the motion is, the less will be the power required to support and advance it." This is just the opposite to the case of the balloon or the ocean steamer, where the necessary energy increases by leaps and bounds with the speed of the moving body, until a limit is reached beyond which it is impos-

sible to go. Professor Langley's remarkable discovery is illustrated in the following table, which shows the weight that can be supported in the air by one horse-power, according to the angle at which the sustaining aeroplane is inclined to the horizon: —

Angle of Aeroplane to Horizon	Soaring Speed (V), in Feet per Second	Horizontal Pressure, in Grammes	Work Expended per Minute, in Foot-pounds	Weight that 1 Horse-power will Drive through Air at Speed V
				Lbs.
45°	36.7	500	2,434	15
30°	34.8	275	1,268	29
15°	36.7	128	623	58
10°	40.7	88	474	77
5°	49.8	45	297	122
2°	65.6	20	174	209

We see, from the last line of this table, that a flying machine whose aeroplanes are inclined at an angle of 2° to the horizon will support a weight of 209 pounds for every horse-power developed by its motor, and will travel at a speed of forty-five miles per hour. Now, it is possible to construct engines — such as that which Sir Hiram Maxim uses in his great flying machine — which weigh no more than 8 pounds per horse-power, so that there is no physical bar to the construction of a flying machine which will rival our express trains in speed, and will carry a large number of passengers. The theoretical establishment of this fact is the greatest of the many debts which we owe to the brilliant genius of Professor Langley.

Unfortunately, it is still too early to believe that the problem of flight is solved, although we are entitled to say that science now pronounces it to be soluble. Several flying machines have been constructed which, as far as their power to fly is concerned, leave little or nothing to be desired. The artificial birds of many inventors, like Pénaud, Le Bris, Pichancourt and Ader, have their lineal descendants in the machines of Sir Hiram Maxim and Professor Langley, which are the most remarkable contributions yet made to the practical solution of the problem of flight. The aerodrome of Professor Langley, driven by a

small steam-engine and supported by aeroplanes which give it a remarkable resemblance to the pterodactyl of prehistoric times, has more than once performed a satisfactory flight of half a mile or more, coming safely to earth again in a fashion which seems to show that its inventor has gone far to overcome the two great difficulties that confront the aeronaut — balance and safe descent. Sir Hiram Maxim admits that he does not yet see his way to solve them, and so his machine — which, unlike the model of Professor Langley, is constructed of sufficient size to carry several passengers — has never been allowed to leave the rails which hold it to the earth. It has frequently shown itself capable of rising from the ground, but its inventor wisely refuses to risk its costly machinery in actual flight. Here is the crux of the matter. As we have seen, the great essential of a flying machine is not only that it should be able to raise itself, but that it should keep its balance in the air. And no one has yet satisfactorily solved this problem. Further, there is the trouble that an accident to a flying machine must necessarily involve the grave injury, if not the death, of its aeronaut, and its own destruction. Only practice in the air can throw light on the difficulties of balance, but it seems almost certain that the first experimenters will not live to tell their tale. Here is a grave hitch. As Mr. H. G. Wells, with his extraordinary faculty of realizing the things that lie outside experience, has said: —

"A man off his feet has the poorest skill in balancing. Even the simple trick of the bicycle costs him some hours of labor. The instantaneous adjustments of the wings, the quick response to a passing breeze, the swift recovery of equilibrium, the giddy, eddying movements that require such absolute precision — all that he must learn with infinite labor and infinite danger, if ever he is to conquer flying. The flying machine that will start off some fine day, driven by neat 'little levers,' with a nice open deck like a liner, and all loaded up with bombshells and guns, is the easy dream of a literary man. In lives and in treasure the cost of the conquest of the empire of the air may even exceed all that has been spent in man's great conquest of the sea. Certainly it will be costlier than the greatest war that has ever devastated the world."

Perhaps this is a heightened and telling way of putting it, but there is much sense in Mr. Wells's argument. Various plans have been suggested for lightening the danger to the

first experimenters with flying machines. Some hold with Dr. Barton, that a balloon should be attached to the aeroplane, to be kept in reserve until the difficulties of balance are overcome. But, as we have shown, the addition of a balloon would probably nullify the qualities of the flying machine, which depends for its support on a speed which would apparently be impossible to attain with so much resistance as the air would present to the surface of the balloon. Others have suggested in all seriousness that condemned criminals should be given a chance for their lives by manning the first air-ships! Others, who are perhaps the most practical, suggest that trials should always take place over water, with a fast torpedo-boat or two in attendance to pick up the aeronauts in case of accident. There would certainly be no harm in the Admiralty taking favorable notice of a request for assistance of this kind. It is possible that the aeronaut might carry a parachute with which to make a leap for life in case of disaster, or even a small balloon which could be speedily inflated from a cylinder of compressed hydrogen — a kind of aerial life-belt. But it is certain that, whatever precautions he adopts, the first man who undertakes to steer a flying machine will need even thicker plates of brass on his heart than Horace ascribed to the first sailor. We fear that the conquest of the air will demand a heavy toll of life and treasure. Yet we do not doubt that it will one day be achieved, if only because the empire of the world lies at the feet of the man who constructs an air-ship that can be converted into a really efficient engine of war.

THE LANGLEY AERODROME.*

By SAMUEL P. LANGLEY.

I HAVE been asked to prepare an account of some experiments I have conducted with flying machines, built chiefly of steel, driven by steam-engines, and which have actually flown for considerable distances. There is in preparation a description of this work for the professional reader; but in view of the great general interest in it, and of the numerous unauthorized statements about it, it has seemed well to write provisionally the informal and popular account which is now given. The work has occupied so much of my life that I have presented what I have to say at present in narrative form.

By "flying machine" is here meant something much heavier than the air, and entirely different in principle from the balloon, which floats only on account of its lightness, as a ship in water. Nature has made her flying machine in the bird, which is nearly a thousand times as heavy as the air its bulk displaces, and only those who have tried to rival it know how inimitable her work is, for the "way of a bird in the air" remains as wonderful to us as it was to Solomon, and the sight of the bird has constantly held this wonder before men's eyes and in some men's minds, and kept the flame of hope from utter extinction, in spite of long disappointment. I well remember how, as a child, when lying in a New England pasture, I watched a hawk soaring far up in the blue, and sailing for a long time without any motion of its wings, as though it needed no work to sustain it, but was kept up there by some miracle. But, however sustained, I saw it sweep, in a few seconds of its leisurely flight, over a distance that to me was encumbered with every sort of obstacle, which did not exist for it. The wall over

* Aërodrome, from words signifying air-runners, the running over the air being the essence of its plan.

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which I had climbed when I left the road, the ravine I had crossed, the patch of undergrowth through which I had pushed my way — all these were nothing to the bird, and while the road had only taken me in one direction, the bird's level highway led everywhere, and opened the way into every nook and corner of the landscape. How wonderfully easy, too, was its flight! There was not a flutter of its pinions as it swept over the field, in a motion which seemed as effortless as that of its shadow.

After many years and in mature life, I was brought to think of these things again, and to ask myself whether the problem of artificial flight was as hopeless and as absurd as it was then thought to be. Nature had solved it, and why not man? Perhaps it was because he had begun at the wrong end, and attempted to construct machines to fly before knowing the principles on which flight rested. I turned for these principles to my books, and got no help. Sir Isaac Newton had indicated a rule for finding the resistance to advance through the air, which seemed, if correct, to call for enormous mechanical power, and a distinguished French mathematician had given a formula showing how rapidly the power must increase with the velocity of flight, and according to which a swallow, to attain a speed it is now known to reach, must be possessed of the strength of a man.

Remembering the effortless flight of the soaring bird, it seemed that the first thing to do was to discard rules which led to such results, and to commence new experiments, not to build a flying machine at once, but to find the principles upon which one should be built; to find, for instance, with certainty by direct trial how much horse-power was needed to sustain a surface of given weight by means of its motion through the air.

Having decided to look for myself at these questions, and at first hand, the apparatus for this preliminary investigation was installed at Allegheny, Pennsylvania, about ten years ago. It consisted of a "whirling table" of unprecedented size, mounted in the open air, and driven round by a steam-engine, so that the end of its revolving arm swept through a circumference of two hundred feet, at all speeds up to seventy miles an hour. At the end of this arm was placed the apparatus

to be tested, and, among other things, this included surfaces disposed like wings, which were hung from the end of the arm and dragged through the air, till its resistance supported them as a kite is supported by the wind. One of the first things observed was that if it took a certain strain to sustain a properly disposed weight while it was stationary in the air, then not only to suspend it but to advance it rapidly at the same time, took less strain than in the first case. A plate of brass weighing one pound, for instance, was hung from the end of the arm by a spring, which was drawn out till it registered that pound weight when the arm was still. When the arm was in motion, with the spring pulling the plate after it, it might naturally be supposed that, as it was drawn faster, the pull would be greater, but the contrary was observed, for under these circumstances the spring *contracted,* till it registered less than an ounce. When the speed increased to that of a bird, the brass plate seemed to float on the air; and not only this, but taking into consideration both the strain and the velocity, it was found that absolutely less power was spent to make the plate move fast than slow, a result which seemed very extraordinary, since in all methods of land and water transport a high speed costs much more power than a slow one for the same distance.

These experiments were continued for three years, with the general conclusion that by simply moving any given weight of this form fast enough in a horizontal path it was possible to sustain it with less than one-twentieth of the power that Newton's rule called for. In particular it was proved that if we could insure horizontal flight without friction, about two hundred pounds of such plates could be moved through the air at the speed of an express train and sustained upon it, with the expenditure of one horse-power — sustained, that is, without any gas to lighten the weight, or by other means of flotation than the air over which it is made to run, as a swift skater runs safely over thin ice, or a skipping stone goes over water without sinking, till its speed is exhausted. This was saying that, so far as power alone was concerned, mechanical flight was theoretically possible with engines we could then build, since I was satisfied that boilers and engines could be constructed to weigh less than twenty pounds to the horse-power, and

that one horse-power would, in theory at least, support nearly ten times that if the flight were *horizontal*. Almost everything, it will be noticed, depends on this, for if the flight is downward it will end at the ground, and if upward the machine will be climbing an invisible hill, with the same or a greater effort than every bicycler experiences with a real one. Speed, then, and this speed expended in a horizontal course, were the first two requisites. This was not saying that a flying-machine could be started from the ground, guided into such flight in any direction, and brought back to earth in safety. There was, then, something more than power needed — that is, skill to use it, and the reader should notice the distinction. Hitherto it had always been supposed that it was wholly the lack of mechanical power to fly which made mechanical flight impossible. The first stage of the investigation had shown how much, or rather how little, power was needed in theory for the horizontal flight of a given weight, and the second stage, which was now to be entered upon, was to show first how to procure this power with as little weight as possible, and, having it, how by its means to acquire this horizontal flight in practice — that is, how to acquire the *art* of flight or how to build a ship that could actually navigate the air.

One thing which was made clear by these preliminary experiments, and made clear nearly for the first time, was that if a surface be made to advance rapidly, we secure an essential advantage in our ability to support it. Clearly we want the advance to get from place to place; but it proves also to be the only practicable way of supporting the thing at all, to thus take advantage of the inertia of the air, and this point is so all-important that we will renew an old illustration of it. The idea in a vague sense is as ancient as classical times. Pope says:

> "Swift Camilla scours the plain,
> Flies o'er the unbending corn, and skims along the main."

Now, is this really so in the sense that a Camilla, by running fast enough, could run over the tops of the corn? *If* she ran fast enough, yes; but the idea may be shown better by the analogous case of a skater who can glide safely over the thinnest ice if the speed is sufficient.

Think of a cake of ice of any small size, suppose a foot

square. It possesses (like everything else in nature) inertia or resistance to displacement, and this will be less or more according to the mass moved. If the skater stands during a single second upon this small mass it will sink under him until he is perhaps waist-deep in the water, while a cake of the same width but twice the length will yield only about half as readily to his weight. On this he will sink only to his knees, we may suppose, while if we think of another cake ten times as long as the first — that is, one foot wide and ten feet long — we see that on this, during the same second, he will not sink above his feet. This is all plain enough; but now suppose the long cake to be divided into ten distinct portions, then it ought to be equally clear that the skater who glides over the whole in a second, distributes his weight over just as much ice as though all ten were in one solid piece. So it is with the air. Even the viewless air possesses inertia; it cannot be pushed aside without some effort; and while the portion which is directly under the air-ship would not keep it from falling several yards in the first second, if the ship goes forward so that it runs or treads on thousands of such portions in that time, it will sink in proportionately less degree; sink, perhaps, only through a fraction of an inch.

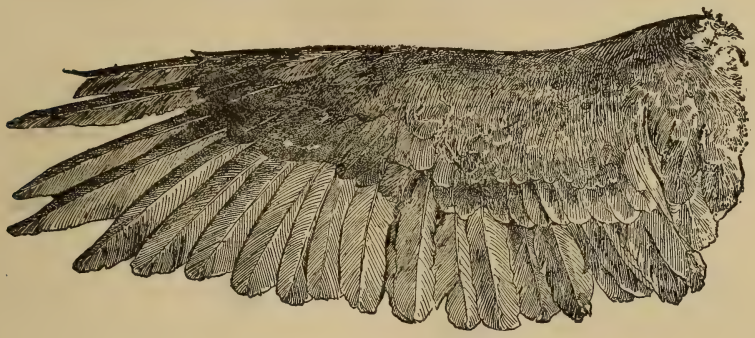
Speed, then, is indispensable here. A balloon, like a ship, will float over one spot in safety, but our flying machine must be in motion to sustain itself, and in motion, in fact, before it can even begin to fly.

Perhaps we may more fully understand what is meant by looking at a boy's kite. Every one knows that it is held by a string against the wind which sustains it, and that it falls in a calm. Most of us remember that even in a calm, if we run and draw it along, it will still keep up, for what is required is motion relative to the air, however obtained.

It can be obtained without the cord if the same pull is given by an engine and propellers strong enough to draw it, and light enough to be attached to and sustained by it. The stronger the pull and the quicker the motion, the heavier the kite may be made. It may be, instead of a sheet of paper, a sheet of metal even, like the plate of brass which has already been mentioned as seeming, when in rapid motion, to float upon the air, and, if it will make the principle involved more clear,

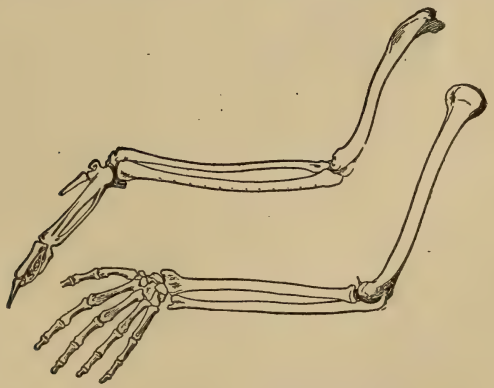
the reader may think of our aërodrome as a great steel kite made to run fast enough over the air to sustain itself, whether in a calm or in a wind, by means of its propelling machinery, which takes the place of the string.

And now having the theory of the flight before us, let us



A Wing From a Soaring Bird.

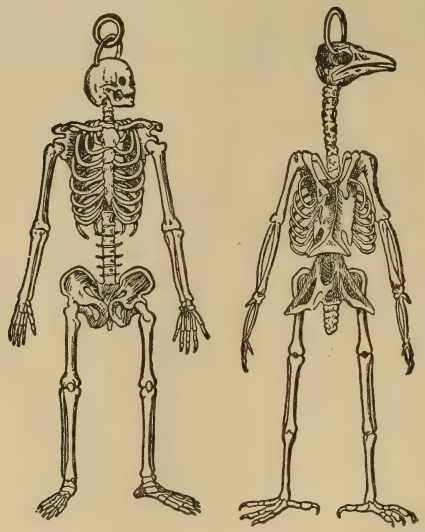
come to the practice. The first thing will be to provide an engine of unprecedented lightness, that is to furnish the power. A few years ago an engine that developed a horse-power,



The Bones of a Bird's Wing and the Bones of a Human Arm, Drawn to the Same Scale, Showing the Close Resemblance Between Them.

weighed nearly as much as the actual horse did. We have got to begin by trying to make an engine which shall weigh, everything complete, boiler and all, not more than twenty pounds

to the horse-power, and preferably less than ten; but even if we have done this very hard thing, we may be said to have only fought our way up to an enormous difficulty, for the next question will be how to use the power it gives so as to get a horizontal flight. We must then consider through what means the power is to be applied when we get it, and whether we shall, for instance, have wings or screws. At first it seems as though Nature must know best, and that since her flying models, birds, are exclusively employing wings, this is the thing for us; but perhaps this is not the case. If we had imitated the horse or the ox, and made the machine which draws our trains walk on legs, we should undoubtedly never have done as well



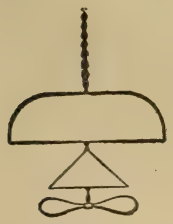
The Skeleton of a Man and the Skeleton of a Bird, Drawn to the same Scale, Showing the Curious Likeness Between Them.

as with the locomotive rolling on wheels; or if we had imitated the whale with its fins, we should not have had so good a boat as we now have in the steamship with the paddle-wheels or the screw, both of which are constructions that Nature never employs. This is so important a point that we will look at the way Nature got her models. Here is a human skeleton, and here one of a bird, drawn to the same scale. Apparently Nature made one

out of the other, or both out of some common type, and the closer we look, the more curious the likeness appears.

Here is a wing from a soaring bird, here the same wing stripped of its feathers, and here the bones of a human arm, on the same scale. Now, on comparing them we see still more clearly than in the skeleton, that the bird's wing has developed out of something like our own arm. First comes the humerus, or principal bone of the upper arm, which is in the wing also. Next we see that the forearm of the bird repeats the radius and ulna, or two bones of our own forearm, while our wrist and finger-bones are modified in the bird to carry the feathers, but are still here. To make the bird, then, Nature appears to have taken what material she had in stock, so to speak, and developed it into something that would do. It was all that Nature had to work on, and she has done wonderfully well with such unpromising material; but any one can see that our arms would not be the best thing to make flying machines out of, and that there is no need of our starting there when we can start with something better and develop that. Flapping wings might be made on other principles, and perhaps will be found in future flying machines, but the most promising thing to try seemed to me to be the screw propeller.

Some twenty years ago, Penaud, a Frenchman, made a toy, consisting of a flat, immovable sustaining wing surface, a flat tail, and a small propelling screw. He made the wing and tail out of paper or silk, and the propeller out of cork and feathers, and it was driven directly by strands of india-rubber twisted lamplighter fashion, and which turned the wheel as they untwisted.



Penaud's Flying Toy (One-eighth of Actual Size).

The great difficulty of the task of creating a flying machine may be partly understood when it is stated that no machine in the whole history of invention, unless it were this toy of Penaud's, had ever, so far as I can learn, flown for even ten seconds; but something that will actually fly must be had to teach the art of "balancing."

When experiments are made with models moving on a whirl-

ing table or running on a railroad track, these are *forced* to move horizontally and at the same time are held so that they cannot turn over; but in free flight there will be nothing to secure this, unless the air-ship is so adjusted in all its parts that it tends to move steadily and horizontally, and the acquisition of this adjustment or art of "balancing" in the air is an enormously difficult thing, and which, it will be seen later, took years to acquire.

My first experiments in it, then, were with models like these, but from them I got only a rude idea how to balance the future aërodrome, partly on account of the brevity of their flight, which only lasted a few seconds, partly on account of its irregularity. Although, then, much time and labor were spent by me on these, it was not possible to learn much about the balancing from them.

Thus it appeared that something which could give longer and steadier flights than india-rubber must be used as a motor, even for the preliminary trials, and calculations and experiments were made upon the use of compressed air, carbonic-acid gas, electricity in primary and storage batteries, and numerous other contrivances, but all in vain. The gas-engine promised to be best ultimately, but nothing save steam gave any promise of immediate success in supporting a machine which would teach these conditions of flight by actual trial, for all were too heavy, weight being the great enemy. It was true also that the steam-driven model could not be properly constructed until the principal conditions of flight were learned, nor these be learned till the working model was experimented with, so that it seemed that the inventor was shut up in a sort of vicious circle.

However, it was necessary to begin in some way, or give up at the outset, and the construction began with a machine to be driven by a steam-engine, through the means of propeller wheels, somewhat like the twin screws of a modern steamship, but placed amidships, not at the stern. There were to be rigid and motionless wings, slightly inclined, like the surface of a kite, and a construction was made on this plan which gave, if much disappointment, a good deal of useful experience. It was intended to make a machine that would weigh twenty or twenty-five pounds, constructed of steel tubes. The engines

were made with the best advice to be got (I am not an engineer); but while the boiler was a good deal too heavy, it was still too small to get up steam for the engines, which weighed about four pounds, and could have developed a horse-power if there were steam enough. This machine, which was to be moved by two propelling screws, was labored on for many months, with the result that the weight was constantly increasing beyond the estimate until, before it was done, the whole weighed over forty pounds, and yet could only get steam for about a half horse-power, which, after deductions for loss in transmission, would give not more than half that gain in actual thrust. It was clear that whatever pains it had cost, it must be abandoned.

This aërodrome could not then have flown; but having learned from it the formidable difficulty of making such a thing light enough, another was constructed, which was made in the other extreme, with two engines to be driven by compressed air, the whole weighing but five or six pounds. The power proved insufficient. Then came another, with engines to use carbonic-acid gas, which failed from a similar cause. Then followed a small one to be run by steam, which gave some promise of success, but when tried indoors it was found to lift only about one-sixth of its own weight. In each of these the construction of the whole was remodeled to get the greatest strength and lightness combined, but though each was an improvement on its predecessor, it seemed to become more and more doubtful whether it could ever be made sufficiently light, and whether the desired end could be reached at all.

The chief obstacle proved to be not with the engines, which were made surprisingly light after sufficient experiment. The great difficulty was to make a boiler of almost no weight which would give steam enough, and this was a most wearying one. There must be also a certain amount of wing surface, and large wings weighed prohibitively; there must be a frame to hold all together, and the frame, if made strong enough, must yet weigh so little that it seemed impossible to make it. These were the difficulties that I still found myself in after two years of experiment, and it seemed at this stage again as if it must, after all, be given up as a hopeless task, for somehow the thing had to be built stronger and lighter yet. Now, in all ordinary construction, as in building a steamboat or a house,

engineers have what they call a factor of safety. An iron column, for instance, will be made strong enough to hold five or ten times the weight that is ever going to be put upon it, but if we try anything of the kind here the construction will be too heavy to fly. Everything in the work has got to be so light as to be on the edge of breaking down and disaster, and when the breakdown comes all we can do is to find what is the weakest part and make that part stronger; and in this way work went on, week by week and month by month, constantly altering the form of construction so as to strengthen the weakest parts, until, to abridge a story which extended over years, it was finally brought nearly to the shape it is now, where the completed mechanism, furnishing over a horse-power, weighs collectively something less than seven pounds. This does not include water, the amount of which depends on how long we are to run; but the whole thing, as now constructed, boiler, fire-grate, and all that is required to turn out an actual horse-power and more, weighs something less than one one-hundredth part of what the horse himself does. I am here anticipating; but after these first three years something not greatly inferior to this was already reached, and so long ago as that, there had accordingly been secured mechanical power to fly, if that were all — but it is not all.

After that came years more of delay arising from other causes, and I can hardly repeat the long story of subsequent disappointment, which commenced with the first attempts at actual flight.

Mechanical power to fly was, as I say, obtained three years ago; the machine could lift itself if it ran along a railroad track, and it might seem as though, when it could lift itself, the problem was solved. I knew that it was far from solved, but felt that the point was reached where an attempt at actual free flight should be made, though the anticipated difficulties of this were of quite another order to those experienced in shop construction. It is enough to look up at the gulls or buzzards, soaring overhead, and to watch the incessant rocking and balancing which accompanies their gliding motion to apprehend that they find something more than mere strength of wing necessary, and that the machine would have need of something more than mechanical power, though what this some-

thing was, was not clear. It looked as though it might need a power like instinctive adaptation to the varying needs of each moment, something that even an intelligent steersman on board could hardly supply, but to find what this was, a trial had to be made. The first difficulty seemed to be to make the initial flight in such conditions that the machine would not wreck itself at the outset, in its descent, and the first question was where to attempt to make the flight.

It became clear without much thought, that since the machine was at first unprovided with any means to save it from breakage on striking against the ground, it would be well, in the initial stage of the experiment, not to have it light on the ground at all, but on the water. As it was probable that, while skill in launching was being gained, and until after practice had made perfect, failures would occur, and as it was not desired to make any public exhibition of these, a great many places were examined along the shores of the Potomac, and on its high bluffs, which were condemned partly for their publicity, but partly for another reason. In the course of my experiments I had found out, among the infinite things pertaining to this problem, that the machine must begin to fly in the face of the wind, and just in the opposite way to a ship, which begins its voyage with the wind behind it. If the reader has ever noticed a soaring bird get upon the wing, he will see that it does so with the breeze against it, and thus whenever the aërodrome is cast into the air, it must face a wind which may happen to blow from the north, south, east, or west, and we had better not make the launching station a place like the bank of a river, where it can go only one way. It was necessary, then, to send it from something which could be turned in any direction, and taking this need in connection with the desirability that at first the air-ship should light in the water, there came at last the idea (which seems obvious enough when it is stated) of getting some kind of a barge or boat, and building a small structure upon it, which could house the aërodrome when not in use, and from whose flat roof it could be launched in any direction. Means for this were limited, but a little "scow" was procured, and on it was built a primitive sort of a house, one story high, and on the house a platform about ten feet higher, so that the top of the platform was about

twenty feet from the water, and this was to be the place of the launch. This boat it was found necessary to take down the river as much as thirty miles from Washington, where I then was,— since no suitable place could be found nearer,— to an island having a stretch of quiet water between it and the main shore; and here the first experiments in attempted flight developed difficulties of a new kind, difficulties which were partly anticipated, but which nobody would probably have conjectured would be of their actually formidable character, which was such as for a long time to prevent any trial being made at all. They arose partly out of the fact that even such a flying machine as a soaring bird has to get up an artificial speed before it is on the wing. Some soaring birds do this by an initial run upon the ground, and even under the most urgent pressure cannot fly without it.

Take the following graphic description of the commencement of an eagle's flight (the writer was in Egypt, and the "sandy soil" was that of the banks of the Nile):

"An approach to within eighty yards aroused the king of birds from his apathy. He partly opened his enormous wings, but stirs not yet from his station. On gaining a few feet more he begins to *walk* away, with half-expanded but motionless wings. Now for the chance, fire. A charge of number three from eleven bore rattles audibly but ineffectively upon his densely feathered body; his walk increases to a run, he gathers speed with his slowly waving wings, and eventually leaves the ground. Rising at a gradual inclination, he mounts aloft and sails majestically away to his place of refuge in the Libyan range, distant at least five miles from where he rose. Some fragments of feathers denoted the spot where the shot had struck him. The marks of his claws were traceable in the sandy soil, as, at first with firm and decided digs, he forced his way, but as he lightened his body and increased his speed with the aid of his wings, the imprints of his talons gradually merged into long scratches. The measured distance from the point where these vanished, to the place where he had stood, proved that with all the stimulus that the shot must have given to his exertions, he had been compelled to run full twenty yards before he could raise himself from the earth."

We have not all had a chance to see this striking illustration

of the necessity of getting up a preliminary speed before soaring, but many of us have disturbed wild ducks on the water and noticed them run along it, flapping their wings for some distance to get velocity before they can fly, and the necessity of the initial velocity is at least as great with our flying machine as it is with a bird.

To get up this preliminary speed, many plans were proposed, one of which was to put the aërodrome on the deck of a steamboat and go faster and faster until the head wind lifted it off the deck. This sounds reasonable, but is absolutely impracticable, for when the aërodrome is set up anywhere in the open air we find that the very slightest wind will turn it over, unless it is firmly held. The whole must be in motion, but in motion from something to which it is held till that critical instant when it is set free as it springs into the air.

The house-boat was fitted with an apparatus for launching the aërodrome with a certain initial velocity, and was (in 1893) taken down the river and moored in the stretch of quiet water which I have mentioned, and it was here that the first trials at launching were made, under the difficulties to which I have alluded.

Perhaps the reader will take patience to hear an abstract of a part of the diary of these trials, which commenced with a small aërodrome which had finally been built to weigh only about ten pounds, which had an engine of not quite one-half horse-power, and which could lift much more than was theoretically necessary to enable it to fly. The exact construction of this early aërodrome is unimportant, as it was replaced later by an improved one, of which a drawing is given on page 58, but it was the first outcome of the series of experiments which had occupied three years, though the disposition of its supporting surfaces, which should cause it to be properly balanced in the air and neither fly up nor down, had yet to be ascertained by trial.

What must still precede this trial was the provision of the apparatus for launching it into the air. It is a difficult thing to launch a ship, although gravity keeps it down upon the ways, but the problem here is that of launching a kind of ship which is as ready to go up into the air like a balloon as to go off sideways, and readier to do either than to go straight for-

ward, as it is wanted to do, for though there is no gas in the flying machine, its great extent of wing surface renders it something like an albatross on a ship's deck — the most unmanageable and helpless of creatures until it is in its proper element.

If there were an absolute calm, which never really happens, it would still be impracticable to launch it as a ship is launched, because the wind made by running it along would get under the wings and turn it over. But there is always more or less wind, and even the gentlest breeze was afterward found to make the air-ship unmanageable unless it was absolutely clamped down to whatever served to launch it, and when it was thus firmly clamped, as it must be at several distinct points, it was necessary that it should be released simultaneously at all these at the one critical instant that it was leaping into the air. This is another difficult condition, but that it is an indispensable one may be inferred from what has been said. In the first form of launching-piece this initial velocity was sought to be attained by a spring, which threw forward the supporting frame on which the aërodrome rested; but at this time the extreme susceptibility of the whole construction to injury from the wind, and the need of protecting it from even the gentlest breeze, had not been appreciated by experience. On November 18, 1893, the aërodrome had been taken down the river, and the whole day was spent in waiting for a calm, as the machine could not be held in position for launching for two seconds in the lightest breeze. The party returned to Washington and came down again on the 20th, and although it seemed that there was scarcely any movement in the air, what little remained was enough to make it impossible to maintain the aërodrome in position. It was let go, notwithstanding, and a portion struck against the edge of the launching-piece, and all fell into the water before it had an opportunity to fly.

On the 24th, another trip was made, and another day spent ineffectively on account of the wind. On the 27th there was a similar experience, and here four days and four (round-trip) journeys of sixty miles each had been spent without a single result. This may seem to be a trial of patience, but it was repeated in December, when five fruitless trips were made, and thus nine such trips were made in these two months,

and but once was the aërodrome even attempted to be launched, and this attempt was attended with disaster. The principal cause lay, as I have said, in the unrecognized amount of difficulty introduced even by the very smallest wind, as a breeze of three or four miles an hour, hardly perceptible to the face, was enough to keep the air-ship from resting in place for the critical seconds preceding the launching.

If we remember that this is all irrespective of the fitness of the launching-piece itself, which at first did not get even a chance for trial, some of the difficulties may be better understood, and there were many others.

During most of the year 1894 there was the same record of defeat. Five more trial trips were made in the spring and summer, during which various forms of launching apparatus were tried with varied forms of disaster. Then it was sought to hold the aërodrome out over the water and let it drop from the greatest attainable height, with the hope that it might acquire the requisite speed of advance before the water was reached. It will hardly be anticipated that it was found impracticable at first to simply let it drop, without something going wrong, but so it was, and it soon became evident that even were this not the case, a far greater time of fall was requisite for this method than that at command. The result was that in all these eleven months the aërodrome had not been launched, owing to difficulties which seem so slight that one who has not experienced them may wonder at the trouble they caused.

Finally, in October, 1894, an entirely new launching apparatus was completed, which embodied the dozen or more requisites, the need for which had been independently proved in this long process of trial and error. Among these was the primary one that it was capable of sending the aërodrome off at the requisite initial speed, in the face of a wind from whichever quarter it blew, and it had many more facilities which practice had proved indispensable.

This new launching-piece did its work in this respect effectively, and subsequent disaster was, at any rate, not due to it. But now a new series of failures took place, which could not be attributed to any defect of the launching apparatus, but to a cause which was at first obscure, for sometimes the aërodrome, when successfully launched, would dash down forward and

into the water, and sometimes (under apparently identically like conditions) would sweep almost vertically upward in the air and fall back, thus behaving in entirely opposite ways, although the circumstances of flight seemed to be the same. The cause of this class of failure was finally found in the fact that as soon as the whole was upborne by the air, the wings yielded under the pressure which supported them, and were momentarily distorted from the form designed and which they appeared to possess. "Momentarily," but enough to cause the wind to catch the top, directing the flight downward, or under them, directing it upward, and to wreck the experiment. When the cause of the difficulty was found, the cure was not easy, for it was necessary to make these great sustaining surfaces rigid so that they could not bend, and to do this without making them heavy, since weight was still the enemy; and nearly a year passed in these experiments.

Has the reader enough of this tale of disaster? If so, he may be spared the account of what went on in the same way. Launch after launch was successively made. The wings were finally, and after infinite patience and labor, made at once light enough and strong enough to do the work, and now in the long struggle the way had been fought up to the face of the final difficulty, in which nearly a year more passed, for the all-important difficulty of balancing the aërodrome was now reached, where it could be discriminated from other preliminary ones, which have been alluded to, and which at first obscured it. If the reader will look at the hawk or any soaring bird, he will see that as it sails through the air without flapping the wing, there are hardly two consecutive seconds of its flight in which it is not swaying a little from side to side, lifting one wing or the other, or turning in a way that suggests an acrobat on a tight-rope, only that the bird uses its widely outstretched wings in place of the pole.

There is something, then, which is difficult even for the bird, in this act of balancing. In fact, he is sailing so close to the wind in order to fly at all, that if he dips his head but the least he will catch the wind on the top of his wing and fall, as I have seen gulls do, when they have literally tumbled toward the water before they could recover themselves.

Beside this, there must be some provision for guarding

against the incessant, irregular currents of the wind, for the wind as a whole — and this is a point of prime importance — is not a thing moving along all-of-a-piece, like water in the Gulf Stream. Far from it. The wind, when we come to study it, as we have to do here, is found to be made of innumerable currents and counter-currents which exist altogether and simultaneously in the gentlest breeze, which is in reality going fifty ways at once, although, as a whole, it may come from the east or the west; and if we could see it, it would be something like seeing the rapids below Niagara, where there is an infinite variety of motion in the parts, although there is a common movement of the stream as a whole.

All this has to be provided for in our mechanical bird, which has neither intelligence nor instinct, without which, although there be all the power of the engines requisite, all the rigidity of wing, all the requisite initial velocity, it still cannot fly. This is what is meant by balancing, or the disposal of the parts, so that the air-ship will have a position of equilibrium into which it tends to fall when it is disturbed, and which will enable it to move of its own volition, as it were, in a horizontal course.

Now the reader may be prepared to look at the apparatus which finally has flown. In the completed form we see two pairs of wings, each slightly curved, each attached to a long steel rod which supports them both, and from which depends the body of the machine, in which are the boilers, the engines, the machinery, and the propeller wheels, these latter being not in the position of those of an ocean steamer, but more nearly amidships. They are made sometimes of wood, sometimes of steel and canvas, and are between three and four feet in diameter.

The hull itself is formed of steel tubing; the front portion is closed by a sheathing of metal which hides from view the fire-grate and apparatus for heating, but allows us to see a little of the coils of the boiler and all of the relatively large smoke-stack in which it ends. The conical vessel in front is an empty float, whose use is to keep the whole from sinking if it should fall in the water.

This boiler supplies steam for an engine of between one and one and one-half horse-power, and, with its fire-grate, weighs a little over five pounds. This weight is exclusive of

that of the engine, which weighs, with all its moving parts, but twenty-six ounces. Its duty is to drive the propeller wheels, which it does at rates varying from 800 to 1,200, or even more, turns a minute, the highest number being reached when the whole is speeding freely ahead.

The rudder, it will be noticed, is of a shape very unlike that of a ship, for it is adapted both for vertical and horizontal steering. It is impossible within the limits of such an article as this, however, to give an intelligible account of the manner

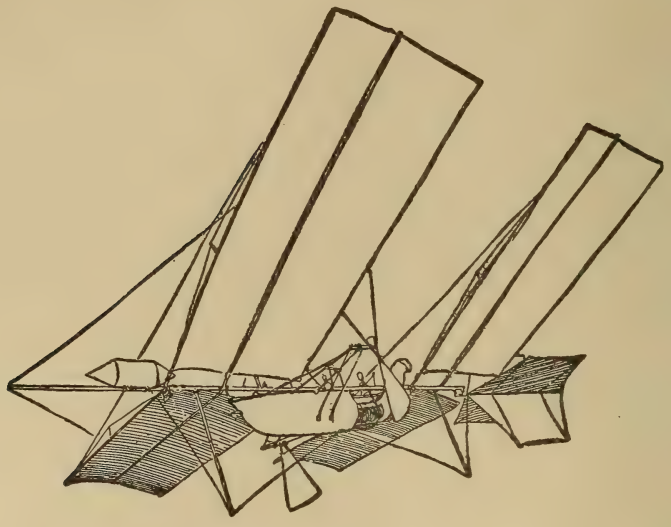


Diagram of the Aërodrome.

in which it performs its automatic function. Sufficient it is to say that it does perform it.

The width of the wings from tip to tip is between twelve and thirteen feet, and the length of the whole about sixteen feet. The weight is nearly thirty pounds, of which about one-fourth is contained in the machinery. The engine and boilers are constructed with an almost single eye to economy of weight, not of force, and are very wasteful of steam, of which they spend their own weight in five minutes. This steam might all be recondensed and the water re-used by proper condensing apparatus, but this cannot be easily introduced in so small a

scale of construction. With it the time of flight might be hours instead of minutes, but without it the flight (of the present aërodrome) is limited to about five minutes, though in that time, as will be seen presently, it can go some miles; but owing to the danger of its leaving the surface of the water for that of the land, and wrecking itself on shore, the time of flight is limited designedly to less than two minutes.

I have spared the reader an account of numberless delays, from continuous accidents and from failures in attempted flights, which prevented a single entirely satisfactory one during nearly three years after a machine with power to fly had been attained. It is true that the aërodrome maintained itself in the air at many times, but some disaster had so often intervened to prevent a complete flight that the most persistent hope must at some time have yielded. On the 6th of May of last year I had journeyed, perhaps for the twentieth time, to the distant river station, and recommenced the weary routine of another launch, with very moderate expectation indeed; and when, on that, to me, memorable afternoon the signal was given and the aërodrome sprang into the air, I watched it from the shore with hardly a hope that the long series of accidents had come to a close. And yet it had come and for the first time the aërodrome swept continuously through the air like a living thing, and as second after second passed on the face of the stop-watch, until a minute had gone by, and it still flew on, and as I heard the cheering of the few spectators, I felt that something had been accomplished at last, for never in any part of the world, or in any period, had any machine of man's construction sustained itself in the air before for even half of this brief time. Still the aërodrome went on in a rising course until, at the end of a minute and a half (for which time only it was provided with fuel and water), it had accomplished a little over half a mile, and now it settled rather than fell into the river with a gentle descent. It was immediately taken out and flown again with equal success, nor was there anything to indicate that it might not have flown indefinitely except for the limit put upon it.

I was accompanied by my friend, Mr. Alexander Graham Bell, who not only witnessed the flight, but took the instantaneous photograph of it which has been given. He spoke

of it in a communication to the Institute of France in the following terms:

Through the courtesy of Mr. S. P. Langley, Secretary of the Smithsonian Institution, I have had on various occasions the privilege of witnessing his experiments with aërodromes, and especially the remarkable success attained by him in experiments made on the Potomac River on Wednesday, May 6, which led me to urge him to make public some of these results.

I had the pleasure of witnessing the successful flight of some of these aërodromes more than a year ago, but Professor Langley's reluctance to make the results public at that time prevented me from asking him, as I have done since, to let me give an account of what I saw.

On the date named, two ascensions were made by the aërodrome, or so-called "flying-machine," which I will not describe here further than to say that it appeared to me to be built almost entirely of metal, and driven by a steam-engine which I have understood was carrying fuel and a water-supply for a brief period, and which was of extraordinary lightness.

The absolute weight of the aërodrome, including that of the engine and all appurtenances, was, as I was told, about twenty-five pounds, and the distance, from tip to tip, of the supporting surfaces was, as I observed, about twelve or fourteen feet.

The method of propulsion was by aërial screw propellers, and there was no gas or other aid for lifting it in the air except its own internal energy.

On the occasion referred to, the aërodrome, at a given signal, started from a platform about twenty feet above the water, and rose at first directly in the face of the wind, moving at all times with remarkable steadiness, and subsequently swinging around in large curves of, perhaps, a hundred yards in diameter, and continually ascending until its steam was exhausted, when, at a lapse of about a minute and a half, and at a height which I judged to be between eighty and one hundred feet in the air, the wheels ceased turning, and the machine, deprived of the aid of its propellers, to my surprise did not fall, but settled down so softly and gently that it touched the water without the least shock, and was in fact immediately ready for another trial.

In the second trial, which followed directly, it repeated in nearly every respect the actions of the first, except that the direction of its course was different. It ascended again in the face of the wind, afterwards moving steadily and continually in large curves, accompanied with a rising motion and a lateral advance. Its motion was, in fact, so steady that I think a glass of water on its surface would have remained unspilled. When the steam gave out again, it repeated for a second time the experience of the first trial when the steam had ceased, and settled gently and easily down. What height it reached at this trial I cannot say, as I was not so favorably placed as in the first; but I had occasion to notice that this time its course took it over a wooded promontory, and I was relieved of some apprehension in seeing that it was already so high as to

pass the tree-tops by twenty or thirty feet. It reached the water one minute and thirty-one seconds from the time it started, at a measured distance of over nine hundred feet from the point at which it rose.

This, however, was by no means the length of its flight. I estimated from the diameter of the curve described, from the number of turns of the propellers as given by the automatic counter, after due allowance for slip, and from other measures, that the actual length of flight on each occasion was slightly over three thousand feet. It is at least safe to say that each exceeded half an English mile.

From the time and distance it will be noticed that the velocity was between twenty and twenty-five miles an hour, in a course which was constantly taking it "up hill." I may add that on a previous occasion I have seen a far higher velocity attained by the same aërodrome when its course was horizontal.

I have no desire to enter into detail further than I have done, but I cannot but add that it seems to me that no one who was present on this interesting occasion could have failed to recognize that the practicability of mechanical flight had been demonstrated.

ALEXANDER GRAHAM BELL.

On November 28th I witnessed, with another aërodrome of somewhat similar construction, a rather longer flight, in which it traversed about three-quarters of a mile, and descended with equal safety. In this the speed was greater, or about thirty miles an hour. We may live to see air-ships a common sight, but habit has not dulled the edge of wonder, and I wish that the reader could have witnessed the actual spectacle.

And now, it may be asked, what has been done? This has been done: a "flying machine," so long a type for ridicule, has really flown; it has demonstrated its practicability in the only satisfactory way — by actually flying, and by doing this again and again, under conditions which leave no doubt.

There is no room here to enter on the consideration of the construction of larger machines, or to offer the reasons for believing that they may be built to remain for days in the air, or to travel at speeds higher than any with which we are familiar; neither is there room to enter on a consideration of their commercial value, or of those applications which will probably first come in the arts of war rather than those of peace; but we may at least see that these may be such as to change the whole conditions of warfare, when each of two opposing hosts will have its every movement known to the other, when no lines of fortification will keep out the foe, and when

the difficulties of defending a country against an attacking enemy in the air will be such that we may hope that this will hasten rather than retard the coming of the day when war shall cease.

I have thus far had only a purely scientific interest in the results of these labors. Perhaps if it could have been foreseen at the outset how much labor there was to be, how much of life would be given to it, and how much care, I might have hesitated to enter upon it at all. And now reward must be looked for, if reward there be, in the knowledge that I have done the best I could in a difficult task, with the results which it may be hoped will be useful to others. I have brought to a close the portion of the work which seemed to be specially mine — the demonstration of the practicability of mechanical flight — and for the next stage, which is the commercial and practical development of the idea, it is probable that the world may look to others. The world, indeed, will be supine if it do not realize that a new possibility has come to it, and that the great universal highway overhead is now soon to be opened.

CIRCLING THE EIFFEL TOWER.

By EUGENE P. LYLE, Jr.

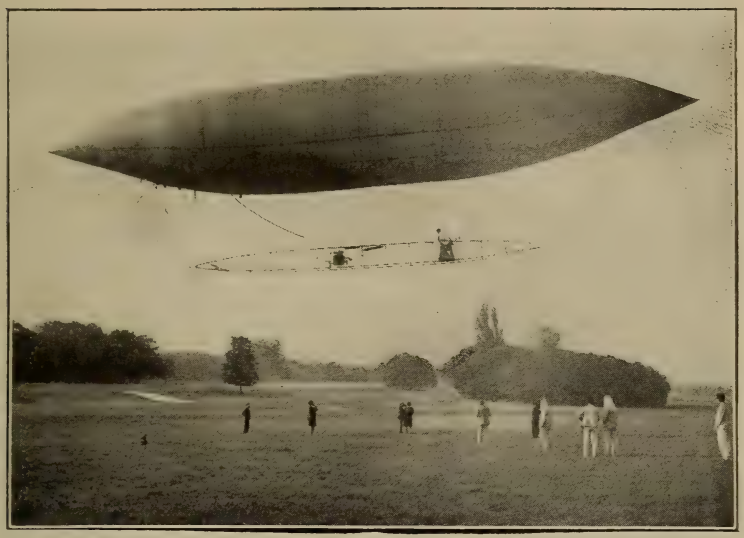
AS early as 3 o'clock of the morning of July 12, 1901, a curious procession emerged from a hillside inclosure on the bank of the Seine and proceeded toward the silent race course of Longchamp across the river. Besides several correspondents, this party was composed mostly of young Parisians, who slowly steered their automobiles while they bent their heads back and looked upward. Following them, a few yards in the air, there floated a strange, mysterious shape, dim and yellowish against the hazy dawn. Several men on foot guided the aerial contrivance by ropes which they clung to jealously. Their care was natural, for they held in leash the first flying machine; and by "flying machine" is meant one that really has flown, and which deserves its name literally, being far, far removed from the monotony of the many failures gone before. But the young Parisians did not know as yet that it would fly, for this was to be its first trial — its debut in the air — and not one among those gathered to witness it suspected that he was to assist at a spectacle which history may possibly compare with the launching of Fulton's steamboat or with the firing of the first locomotive.

At the race track the balloon was pulled down till the framework rested on the ground. A young man, 25 years of age, went hurrying about the air-ship, tinkering at it here and there till the very last moment, while his comrades of the Automobile and Aero clubs looked on and respectfully let him have his way. He was a very little man, in shirt sleeves and a high collar, with an almost effeminate speech, and very amiable, but he seemed to know pretty well what he was about. When he had examined the tube which connects a cigar-shaped gasoline tank with the motor, he wrapped a strap around a wheel of the motor, pulled the strap off again with a sharp jerk, and

thus set the motor going. Involuntarily the spectators jumped back, for the gasoline engine with its four cylinders starts with a crashing explosion, so closely followed by others that the deafening, bursting combustion is almost continuous; yet through the framework there is scarcely any vibration at all, only a slight quivering.

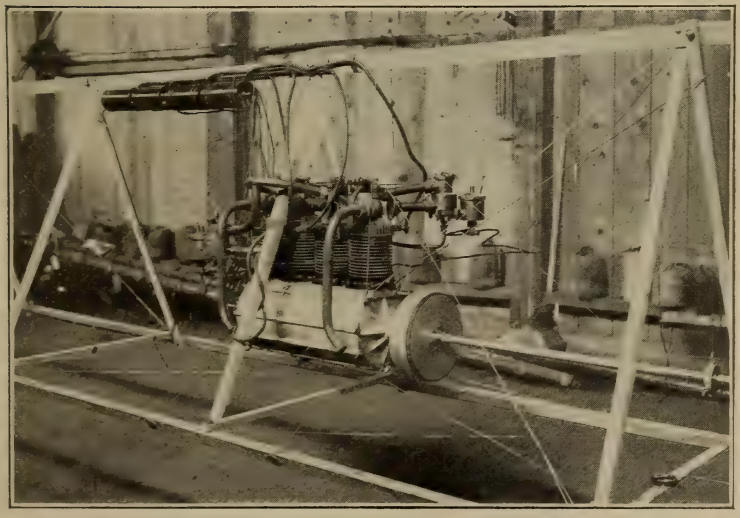
Before climbing into his basket, the slender little aeronaut took a final look up at the sky. He had spent the last two nights near his balloon, patiently waiting for favorable weather. He seemed satisfied now, and climbed into his tiny car, which is just a narrow crating of willow fixed into the forward nose of the triangular framework. The guide rope was slackened and the balloon lifted him slowly from the ground. He gave a signal and the guide rope was released. The balloon bounded into the calm air. Those below, bending back their necks, saw in the stern two big fans, the screw of the vessel, begin to turn. They watched breathlessly, for the question of that moment was, Would those fans serve as wings, or would the balloon prove only a balloon after all, obeying no will other than that of the breeze? That has ever been the question when some outlandish contrivance would mount into the air, and hitherto the answer at best has been only a sadly qualified negative. But this latest contrivance of the series appeared to be acting deliberately and rationally. She pointed her nose slightly upward and rose higher. Her rudder shifted and she slowly began to turn, and, following the track, made the circuit of the race course. On nearing the spectators the vessel pointed her nose downward and slowly descended. A moment later the little aeronaut climbed from his basket to the ground as one might alight from a bicycle. But the blood was stinging in his face, and joy fairly burned in his eyes. He appreciated, though only vaguely, what he had done. He had been striving to do this same thing with one balloon after another for a number of long, patient years. Before night of that day his name was known all over the world.

Once more, then, this little Brazilian aeronaut, Alberto Santos-Dumont, climbed back into his basket. He said that he would make the round again, and with a gesture indicated his intended landing place. He mounted as easily as before, swept around the track, and descended neatly on the spot he had



PRELIMINARY TRIAL OF SANTOS-DUMONT'S AIRSHIP.

Leaving for the Trocadero.



SIXTEEN-HORSE-POWER MOTOR USED BY SANTOS-DUMONT.

The motor gives the screw 200 revolutions a minute.

pointed out. This was certainly an accumulating of evidence, and he had to believe that this last air-ship of his, the *Santos-Dumont V,* had proved a success on her first trial. It was as simple as spinning around the track on an automobile. Four more times he did the same thing. His chariot was perfectly manageable, and answered the rudder as docilely as a good horse does the reins. During all the experiments of that morning he had no recourse whatever to ballast, and was yet entirely master of his altitude. This was due to the guide rope, a heavy cord several hundred feet long, hanging from the forward nose of the car. By pulling it toward the center of equilibrium or letting it out again, he could incline the axis of the balloon, pointing her up or down, and then, by propulsion of the fans, he could mount higher or drop lower at will. Sometimes he attained a speed of 25 miles an hour.

These triumphs tending to make him more ambitious, he bade his friends au revoir and sailed off for the near-by station of Puteaux, returning very soon without touching ground. It was now that he declared for the little flying trip around Eiffel Tower. He refilled his petroleum can and off he started at an encouraging rate, while his friends stared after him, still too dazed for the hysterics of enthusiasm which were soon to possess them.

The distance from Longchamp to the tower is a little more than three miles, but the air-ship made it in ten minutes, keeping at an altitude of from 100 to 300 yards. It is difficult to imagine what must have been the astonishment of early-morning visitors on the tower when they saw a man in a flying machine come soaring near them and genially wave them his greetings.

The bizarre traveler rounded the tower and was returning whence he came when one of the gear cords of his rudder broke. So, as naturally as a wheelman dismounts to repair a puncture, he came down into the Trocadéro Gardens, borrowed a ladder, climbed up the side of his balloon, tied the cord, and remounting, proceeded on his way back to Longchamp. Counting in the delay, he had been gone one hour and six minutes.

By this time the party at the race course had recovered sufficiently from their amazement for more or less intelligible

congratulations. He had solved the fatuous problem of aerial navigation — that was their refrain. And almost the entire press of that day supported their words. He had undoubtedly steered a balloon. The two essentials were there, and they had worked effectively, namely, the propeller and the rudder. He had sailed the four points of the compass, he had sailed in circles, and he had sailed up and down, and the bulky aerostat of Count Zeppelin over Lake Constance was now rated as an insignificant step, while the real, great stride had just been achieved by the young Brazilian. So his companions insisted that he should try at once for the Grand Prix.

Now it should be explained that the Grand Prix referred to is the official goal of balloonists. A wealthy member of the Aero Club, Henry Deutsch, founded the prize last year. The amount is $20,000, but the conditions seemed too preposterous; very ingenious, only impossible. The conditions prescribe that the winning aeronaut shall start in his air-ship from the Aero Club Park (the inclosed hillside on the Seine near Longchamp), sail to and around the Eiffel Tower, and return and land in the park, a trip of about eight miles, without touching ground or aught else in the meantime, and all within the maximum time limit of a half hour. Although this offered a definite incentive to plunge into what was one of the most fascinating impossibilities of the future, only the flying machine inventors — the synonym of a disordered mind — regarded flying machines with any respect. This fascination had long enslaved the rich young Brazilian, when one day the Grand Prix was founded, and he constructed his *Santos-Dumont IV* to win it, seeking thereby the official recording of a definite triumph. For him the $20,000 would be merely a little purse for the building of more air-ships. But before he housed his aerial pet, *Santos-Dumont V,* in the balloon shed at the park that morning of July 12, he announced to his friends that he would try again for the Grand Prix.

At 4 o'clock the next morning, July 13, the sky was mottled with clouds, while a choppy wind blew from the west; but as there was no change for the worse by 5 o'clock, Santos-Dumont began making preparations for his flight. Long before he was through with testing the parts of his machine, a crowd had begun to gather in the park — wheelmen, chauffeurs, pho-

tographers, and correspondents. At 6.20 the great sliding doors of the balloon house were pushed open, and the massive inflated occupant was towed out into the open space of the park. The big, pointed nose of the balloon and its fish-like belly resembled a shark gliding with lazy craft from a shadow into light waters. In the basket of the car stood the coatless aeronaut, who laughed and chatted like a boy with the crowd around him. The prize committee was there and expressed its hopes for a successful trial. This committee is composed of Count Henri de la Vaulx, the vice-president of the Aero Club, who intends shortly to cross the Mediterranean in a balloon; Prince Roland Bonaparte, Henry Deutsch, and two members of the National Institute, MM. Bouquet de la Grye and Cailletet.

From the very first the conditions did not show themselves favorable for the attempt. The wind was blowing at the rate of six or seven yards a second. The change of temperature from the balloon house to the cool morning air had somewhat condensed the hydrogen gas of the balloon, so that one end flapped about in a sadly flabby manner. Air was pumped into the air reservoir, or ballonet, inside the balloon, but still the desired rigidity was not attained. But, more discouraging yet, when the motor was started, its continuous explosions gave to the practiced ear signs of mechanical discord. It should be stated that this motor can be started only from the ground, by the strap twisted around the wheel, as already mentioned. Once the motor stops while in air, there is no way to set it going again without coming down to earth.

Nevertheless, Santos-Dumont, with his sleeves rolled up, fixed himself once more in his basket with much the same air as a workman seats himself before his lathe for the day's work. His eye took a careful survey of the entire air-ship lest some preliminary had been overlooked. He counted the ballast bags under his feet in the basket, he looked to the canvas pocket of loose sand at either hand, then saw to his guide rope. Everything appeared to be all right. Several friends shook his hand, among them Mr. Deutsch. Count de la Vaulx, with watch in hand, stood ready to begin counting the official time. The chattering stopped, and the place was very still as the man holding the guide rope awaited the signal to let go. Then the little man

in the basket above them raised his hand and shouted. On the second the timekeeper (Count de la Vaulx) called off 6.41, and man and balloon would have to be back by eleven minutes after 7.

At first it did not look like a race against time. The balloon rose sluggishly, and Santos-Dumont had to dump out bag after bag of sand, till finally the guide rope was clear of the trees. All this gave him no opportunity to think of his direction, and he was drifting toward Versailles; but while yet over the Seine he pulled his rudder ropes taut. Then slowly, gracefully, the enormous spindle veered round and pointed its nose toward the Eiffel Tower. The fans spun energetically, and the air-ship settled down to business-like traveling. It marked a straight, decided line for its goal, then followed the chosen route with a considerable speed. Soon the chug-chugging of the motor could be heard no longer by the spectators, and the balloon and car grew smaller and smaller in its halo of light smoke. Those in the park saw only the screw and the rear of the balloon, like the stern of a steamer in dry dock. Before long only a dot remained against the sky, but the dot was still moving. Steadily it neared the shadowy obelisk line which was Eiffel Tower, then scarcely visible in the heat mist of Paris. Suddenly the dot vanished behind the tower, thus bringing together man's two ways of getting into the air, the one from a century just closed, the other from a century just beginning.

To the throng waiting in the park the dot seemed blotted from sight for a long while, but at last they could distinguish it emerging from the foggy ladder-shape outlined against the sky. They could not tell, however, whether it had really gone around the tower. If Santos-Dumont had not doubled the tower, then the greater interest in his return was lost. It would be no longer a race. Still the people kept count of the minutes as they watched the speck grow larger and larger, and gradually evolve into the form of an air-ship. The morning sun caught on the burnished copper of the petroleum reservoir, and the man could be seen in his car, and then a messenger in an automobile raced up to the park gate. He brought the marking of the official timekeeper on Eiffel Tower, and his announcement laid all doubts. The *Santos-Dumont V* had doubled the tower, he announced, passing 20 yards to leeward, time 6.54.

That meant half the journey in thirteen minutes, a gain of two minutes.

The crowd gazed upward to the still distant balloon, and some in their enthusiasm yelled to the aeronaut to hurry, hurry faster. The Grand Prix was won, of that everybody was certain. But as the minutes were counted off, and the balloon did not seem to be approaching with the speed expected, doubts began to grow among the eager ones. Only four minutes left, only three. Was he going to lose, after all? There he was, steering far above the river, and they could even hear the popping of his motor. Evidently something was wrong. The air-ship labored desperately in the face of the wind, and when at last it hovered over the park the time was 7.22 — eleven minutes late. And yet he had not landed. Instead, the wind swept him back across the river. Twice he returned with extreme difficulty; and then, suddenly, the motor stopped. With that the *Santos-Dumont V* was as an ordinary balloon, and she went with the wind, off over the Bois de Boulogne. A moment later she came down heavily and disappeared in the trees.

A dozen friends sprang to their automobiles and raced away in that direction. Each one dreaded finding Santos-Dumont probably mangled and lifeless. They found him on his feet, with his hands in his pockets, reflectively looking up at his air-ship among the top branches of some chestnut trees in the grounds of Baron Edmund de Rothschild, Boulevard de Boulogne.

"I should like to have a glass of beer," he announced, which called forth a nervous laugh of relief.

Now, next door to Rothschild lives His Royal Highness, the Comte d'Eu, and from a window Her Imperial Highness, the Comtess d'Eu, had been watching the antics of the flying machine and its finale. Her imperial highness is a daughter of Dom Pedro, of Brazil, and consequently a compatriot of young Santos-Dumont. As there ought to be a princess somewhere in an air-ship story, it proved quite convenient that her imperial highness lived next to the Baron Edmund de Rothschild, for she sent over a hamper of champagne and refreshments, with kind inquiries. Santos and his rescuers disposed of the champagne and refreshments; and then Santos, coatless, dusty, and mussed up, hurried over to thank the princess. Her highness

spoke words of encouragement and pointed to Dom Pedro's picture, and then Santos went back to untangle his air-ship from the chestnuts.

When he had cut the wires between the balloon and the car, he discovered, greatly to his surprise, that the damage was really nothing. The delicate skeleton framework was unhurt, except for a slight spraining of the propeller shaft. Then the young man was jubilant, for his treasure had certainly looked like a wreck. He could listen to questions at last, and he gave his story of the flight and fall, which you may be sure was listened to eagerly. To say nothing of the strong wind he had to fight against in coming back, his chief trouble was with his motor. Soon after going up one of the cylinders had stopped, and a little later a second. As he could not restart them, his motive power was thus cut down one-half for the rest of the trip, the motor at last giving out altogether. The wind, of course, carried him back over the river, and as he did not wish to come down in the streets of Boulogne beyond, and perhaps on top of somebody, and be taken up for reckless ballooning, he decided to come down quick where he was. So he ripped out a panel of silk and found himself in the tree tops.

But, after all, the only thing that kept him from winning the prize was the time limit. It must be considered, however, that the donor asks the competitors to do something in a half hour which has never been done before, although men have been trying for a century, and that is to steer a balloon. Weighed against a century, a delay of eleven minutes can not count for much against success.

Within a week the *Santos-Dumont V* was all shipshape again, and awaiting good weather for another try at the Grand Prix. The weather, though, had been unobliging, and Parisians had haunted the Aero Club Park in vain. Sunday, August 4, Santos-Dumont did, in fact, start for another trial, but he had not gone a quarter of the distance when he turned around and came back. The guide rope was not working right. Another spectacle, however, rather offset the popular disappointment. When fully 600 feet in air, the plucky little fellow climbed out of his backet and moved around on the slender framework to adjust a cord that did not suit him.

It was on August 8, 1901, that M. Santos-Dumont made a

third trial for the Grand Prix, with the odd-looking air-ship constructed of two cigar-shaped balloons, with the car for the basket and motors suspended between them. Instead of disaster and destruction, he began with every prospect of success, and strengthened his claim as a navigator of the air. He started from the park at 6.12 a. m., under the best of conditions. His balloon rose quickly in the almost absolute calm, so that without loss of time he started the screw and veered round in a straight line for Eiffel Tower. The trip there was as a bird's flight, clean-cut and unswerving. He gained and rounded the tower in nine minutes, a gain of four minutes over his first trial, or less than one-third of the time limit. He had, therefore, twenty-one minutes in which to make the same trip back. It would be stubborn hard luck that could keep him from the prize. But that is what happened.

The tower was no sooner rounded than difficulties seemed to begin. Without apparent cause the air-ship suddenly pointed upward, and mounted 100 yards higher in air. Then it began to sink toward the roofs, bereft of buoyant force or vitality. It was beyond control, and its navigator was being tossed in mid-air, more helpless than a sailor clinging to a plank. He started the ventilators, to inflate the ballonet with air and make the balloon rigid, but as a climax to despair the ventilators would not work. The balloon became flabby, and even its ends doubled on itself like a pocketknife. This brought the wires that suspend the framework into trouble with the turning screw, and in a moment several of them snapped. Just in time to save himself from being cut away from the balloon entirely and dashed to the ground, Santos stopped the screw, and then the unwieldy air-ship dragged lower to the earth, and was soon skimming over some high hotels that had been built for the exposition. Once he was jolted against a cornice, and once again he was so low that his guide rope coiled along the ground. A carpenter seized the end and wrapped it around the iron bars of a window. But the breeze carried the balloon on, and with a jerk the guide rope tore out the iron bars. On the edge of the next hotel roof the balloon was stranded and wrecked. The framework, though, holding the heavy motor and the man, dangled from its wiring over the wall of the building. A moment it hung suspended, then its lower end settled on the

roof of a two-story restaurant next door, and its upper end against the wall of the hotel. There was a space between the two buildings, and the framework spanned this space almost perpendicularly. The delicate wooden beams strained and cracked, ready to break and bring its load to the ground.

A company of firemen were on hand almost at once, and from the top of the hotel they threw a rope to Santos-Dumont, who tied it around his waist and allowed himself to be drawn up. He had not suffered a scratch, but he suffered much more than that when the firemen began to extract his beloved air-ship. With each cracking of wood he shuddered as though it were a bone; yet despite his anxiety and the care of the firemen, the framework broke into halves, and was soon found to be irreparable, and the same fate met the balloon. The only consolation was the motor, which seemed to be unhurt.

"Now, what are you going to do?" one of his friends demanded.

"Why, begin again, of course. One has to have patience."

And that same day he gave orders for another balloon, which will be the balloon of the air-ship *Santos-Dumont VI.* The new air-ship will be on the same pattern as the old, except with a slightly greater cubic capacity. It can hardly be ready for a prize trial, however, before the contests next spring. Still, Santos-Dumont knows now that he can navigate the air, and he is merely going to do again what he has already done.

But M. Santos-Dumont will soon have competitors, among them M. Deutsch himself, who expects to put in the field within a short time a colossus 65 yards long, with a capacity of over 2,500 cubic yards, and a gasoline motor of 60 horse-power.

Recall the flying machine of your imagination, and you will have ready-made for your mind's eye a likeness of this *Santos-Dumont V.* It is simply that conventional creature pictured in the usual wild tale of the future, the regulation cigar-shaped thing 'mid a vague complication of wings and rudders and cords and cylinders. The gas bag is a tremendous cigar, while the framework beneath for basket and motor is a smaller tremendous cigar. Now, there is a reason for this shape quite apart from the demands of twenty-first century romances. It would be as absurd to try to steer a spherical balloon as to guide a spherical steamboat. The spindle form offers less resistance

to air-currents, so almost from their earliest experiments the flying machine architects have adopted the cigar for a model. To secure rigidity they put an air balloon, or ballonet, inside the gas balloon, and when a cooling cloud or change of temperature contracts the gas, they pump air as needed into the ballonet, which makes the entire bag tight and snug. Santos-Dumont first fills his balloon as full as possible with pure hydrogen, and the inner balloon lies empty in the belly of the big one. He thus has as a margin against condensation the ballonet's capacity, 50 cubic yards. The ballonet fills with air automatically from a pump worked by the motor, and in case of expansion and too great pressure the springs in the valves are forced open and the air is let out first, and the gas afterwards, if necessary. In the photographs you may see the air duct hanging from the balloon to the pump.

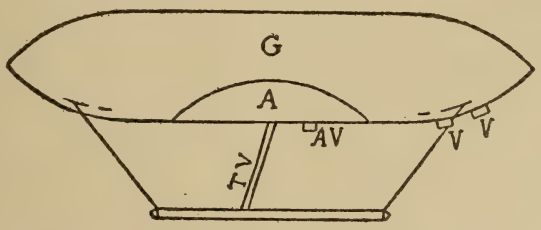


FIG. 1. DIAGRAM OF SANTOS-DUMONT'S BALLOON.
G Represents the Large Balloon Filled with Hydrogen; A, the Interior Air-balloon; VV, Automatic Gas Valves; AV, the Air Valve; TV, the Tube by Which the Rotary Ventilator Fills the Interior Air-Balloon.

The tiny steel threads that suspend the framework seem absurdly inadequate. Near the ends they are twisted into springs, which allow for a slight rocking caused by the motor's vibration. A few yards away the fine piano wires are invisible, and then the man in his aerial car appears to follow as a satellite under the balloon. The great yellowish bag of hydrogen, 37½ yards long, 6½ yards in diameter, with a capacity of 715 cubic yards, looks sleek and peeled, like the pigskin of an enormous Rugby football, and nothing at all like silk. Each panel in the texture has been rigorously tested under pressure and is capable of the maximum strain exacted. The elongated, triangular car beneath is constructed of three slender unpainted pine beams with cross-pieces. When examined as it lies stalled

the long length of the balloon house, this car appears altogether too delicate for carrying a man and an engine several hundred yards over the house-tops. Though over 59 feet long, it weighs only 110 pounds, and early in the spring of 1900 the inventor was able to pack it in his trunk by sections, bringing it from Nice, where it had been made during the winter, to Paris. The carefully chosen strips, bent to form the long curves of the triangular frame complete, are never thicker than two of your fingers put together. During this spring he remounted them in his workshop at the Aero Club Park, the workshop being also the great barn of a balloon house. He made the joints of aluminum and fastened the cross-pieces with thin steel wire. About 8 yards from the stern he suspended the gasoline automobile motor from the upper beam of the triangle by piano wires. Here the compact little engine of 4 cylinders and 16 horse-power hangs like a spider in the center of her web. Over each cylinder spins a ventilating fan to prevent overheating. The motor turns a shaft, and attached to the shaft is a propeller, exactly like the screw of a ship. The two wings of the screw are of silk stretched over their frames like the head of a drum. They measure 4½ yards. Ordinarily the industrions little motor spins the shaft around at the rate of 200 revolutions to the minute; but since putting things into shape after his descent of July 13 the inventor has been able to increase the speed to 210 revolutions a minute. The whirling pinions then have a striking force of 175 pounds. Above the propeller and under the tail of the balloon is the rudder, a curved triangular blade made in the same way as the wings. As both propeller and rudder are thus placed at the stern, the forward end is left free for the guide rope, by which the air-ship may be inclined upward or downward. By this device the aeronaut may ascend or descend. In his former balloons he used sliding ballast bags at either end to maintain his equilibrium, but in this last balloon he had been able to discard these.

To readjust the balance against the motor, as well as to equalize the strain on the wires suspending the framework, the basket is placed forward of the center by nearly 8 yards. This basket is a deep, narrow affair of open willow work. A larger man than the wiry aeronaut would have to squeeze to climb into it. On either side a narrow wooden bar stretches out 3 or 4 yards,

which is designed to prevent undue tipping to one side or the other. As the pilot stands there in his basket he resembles a performer on a tight rope with his balancing pole. Since the head of the concern is in the basket, all the many wires that operate one thing or another communicate with this central administrative bureau like the nerves with the brain. On the front edge of the basket is a wheel, really the pilot's wheel, but placed horizontally as on an automobile. This operates the rudder. To switch the propeller shaft from the motor and stop the fans there is an electric key. For each of the valves in the belly of the balloon there is a wire end at the basket, besides still another one for the big valve in the top should the balloonist wish to descend rapidly, and, yet again, there is an emergency cord, which tears a panel out of the silk and lets the gas fairly pour out. It was this cord that Santos-Dumont pulled when he chose the Rothschild chestnut trees between the Seine and the streets of Boulogne. As to ballast, he has small bags of sand under his feet and a canvas bag on either hand, about 100 pounds in all. Thus, it will be seen that he has several things to think about at the same time. Though seemingly very complicated, this air-ship that really navigates the air is, after all, a simple machine, and by the side of the wonderfully made air-ships that yet do not navigate the air it is a child's toy for simplicity. It is one-fourth as large as the Zeppelin balloon. In fact, it is the smallest motor aerostat that has been constructed up to date. The entire car complete weighs but 550 pounds.

To arrive at this result, which is conceded to be the first actual steerable air-ship, Santos-Dumont has tinkered away some five preceding balloons. He came to Paris expressly to make his career in the air. He made farewell to the plantation of his father, the Brazilian coffee king, where as a boy he had speeded locomotives, real compounds, over the premises. He abandoned these toys and took up with what the French love to call the most French of inventions, flying machines. He allied himself with those rich young Parisians who seek amusements more chic than gilded dissipation; that is, the more intellectual, though scarcely more rational, pursuit of bizarre methods of locomotion. Though able to have stables, and yachts, and palace cars, they prefer automobiles and balloons. The

youthful Alberto began by climbing Mount Blanc to see what high altitudes were like. Then, in 1898, he ordered himself a balloon and called it the *Brésil.* It was a ludicrously small affair, of not more than 145 cubic yards. He would return from a trip with the balloon in his grip. But he was not content. The *Brésil* was spherical, unsteerable — in a word, old fashioned. He put the motor of his automobile into the basket, and was thus the first to apply gasoline to aerial navigation. But as yet the results were not important. That same fall he launched the *Santos-Dumont I,* the first of his cigar-shaped experiments. But the weight of the basket 10 yards beneath made the balloon cave downward, and the air-ship and man tumbled 500 yards to earth without getting hurt — a mere incident. Next year appeared the second *Santos-Dumont,* of the same form, but a little longer. He went up Ascension Day, became dissatisfied, and began work on his No. 3. This one was 22 yards long, with a capacity of 650 cubic yards. The motor worked well, and he made several encouraging ascensions near Eiffel Tower.

Last year, with his No. 4, he had tried for the Deutsch prize, but was awarded only the annual interest of about $760 on the principal amount for having done the most for aerostation during the year. He promptly returned the money and founded a new prize with it, to be awarded for the first trip around Eiffel Tower, no time limit. He had the foresight to bar himself from this competition. The *Santos-Dumont IV* had a capacity of 546 cubic yards, with a 9-horse-power, 2-cylinder motor giving 100 revolutions a minute to the screw. The engine and a bicycle saddle were perched on a bar suspended under the balloon. He started the engine by working the pedals under the saddle, and by cords he controlled the electric lighting of the motor and the management of the rudder, ballast, and equilibrium. He made almost daily flights with this balloon, then later on put in a 16-horse-power engine. This, of course, made a larger gas bag necessary, but he simply cut in half the one he had and lengthened it to 36 yards, as you would a dining-room table. Soon after this the autumn air gave him pneumonia, and he had to go to the Riviera, where he began work on No. 5, his latest pet.

Now that you have followed the inventor through the whole

story, you are beginning to demand where, after all, is the great monumental and mysterious secret of aerial navigation that has been discovered. You have not stumbled upon the trace of one. There has not been a single new mechanical principle involved. The fact is, there has been no secret to discover. The secret of aerial navigation was already discovered when the first automobile with a gasoline motor was built. When Santos-Dumont robbed his automobile of its motor and strapped it into the car of his balloon, he was on the right track. But he certainly had achieved nothing that he could patent. The secret may also have been discovered when the steam-engine was invented, or again when electricity was chained down to man's service, only up to the present there is this fact, namely, no one so far has been able to make a steam-engine or an electric battery run an air-ship. That may happen later, but meantime the gasoline motor does the work for Santos-Dumont. And now the question is, Why does it, rather than either steam or electricity? The entire answer lies in this one word — "weight."

When away back in 1783 the crinoline skirt of Madame de Montgolfier, drying before the fireplace, filled with hot air and puffed up to the ceiling, this same word, "weight," became the keynote of battle and the problem in ballooning. Joseph Montgolfier had beheld the antics of his wife's skirt, and the word that involves the riddle and the solution spelled itself on his brain. That is, he reflected that the inflated crinoline had become lighter than air. So he set to work and astounded the world with the first balloon, an humble paper globe filled with hot air that soared upward but a few yards. Thus having once got into the air, man has ever since been trying and trying to steer himself while there. But any motor that would be powerful enough has always made the balloon heavier than air. For instance, Henri Giffard in 1852 tried steam as motive power, and he was the first to adopt the cigar-shaped bag, but his engine would not propel the balloon, simply because it had to be too light for the power exacted of it. Twenty-five years later Dupuy de Lome went back to first principles and tried manpower, but the man was even less adequate than Giffard's feeble engine. In 1883 another Frenchman, Tissandier, experimented with electricity, but as his batteries had to be light enough to be taken up in the balloon, they proved effective

only in helping to weigh it down to earth again. Krebs and Renard, military aeronauts, succeeded better with electricity, for they could make a small circuit with their air-ship, provided only that no air was stirring. Enthusiasts cried out that the problem was solved, but the two aeronauts themselves, as good mathematicians, figured out that they would have to have a motor eight times more powerful than their own, and that without any increase in weight, which was an impossibility at that time.

Shortly after this, though, people began to drive round in carriages without horses, and their motive power was the gasoline engine. Tissandier's electro motor weighed 375 pounds per horse-power; Santos-Dumont's petroleum motor, 12 pounds per horse-power. In both cases fuel and all accessories are included. Now, just exactly in this enormous difference of weight lies the secret of aerial navigation as solved the other day by the young Brazilian.

The explanation why the petroleum motor is such a tremendous giant for its size is very simple. The greater part of its fuel is in the air itself, and the air is all around the balloon, all ready for use. The aeronaut does not have to take it up with him. If he did, he would be crushed to earth with the weight of his reservoir. But that proportion of his fuel that he must carry, the coal-oil can, is comparatively insignificant. The difference between carrying this fraction and carrying all the fuel, as for steam or electricity, makes the difference between the newer kind of motor and the two old kinds. A few figures will prove startling. Two and one-half gallons of gasoline, weighing 15 pounds, will make a 2½-horse-power autocycle cover 94 miles in four hours. Santos-Dumont's balloon needs less than 5⅓ gallons for a three hours' trip. It weighs but 37 pounds, and occupies the slender cigar-shaped brass reservoir which you will notice near the motor. Now, then, an electric battery of the same power would weigh 2,695 pounds, and yet would last only twenty-five minutes. If we consider the weight and volume of fuel in the air which the gasoline motor does not have to carry up, we will see, on accepting chemistry's word, that a liter of gasoline (3½ pints) consumes during combustion 5.45 pounds of oxygen in the air, which means 27¼ pounds of air. Imagine, therefore, a balloon carrying a reservoir of air for its motor. One liter of gasoline would require an air maga-

zine a yard square and as high as a four-story house. For Santos-Dumont's oil can this magazine would have to be 1,000 feet high, or about big enough to hold the Statue of Liberty.

As to what this last air-ship really means for aerostation, French opinion differs to the overheating point. Again "weight" is the battle cry raised in the two opposing camps of balloonry. One camp maintains that the balloon lighter than air is the beginning and end of the question, and consequently they hold that Santos-Dumont has found the ultimate solution, because he can steer his inflated chariot. Their opponents give the Brazilan big credit for making a dirigible flying machine of any kind, but they contend that the problem rests unsolved so long as the air-ship is not heavier than air. The discussion has grown quite ardent. There are liable to be some duels most any time if cold weather does not set in.

The lighter-than-air people argue that on an aeronef or aeroplane (heavier-than-air machine) the operator would be at the mercy of his motor. If the motor stopped, the air-ship would come down like a clod, having, of course, no gas bag to hold it up. The heavier-than-air contingent admit that this is a point to be considered, and that, therefore, the motor will have to be a very reliable motor indeed. And then they proceed to point out that the aerostat (lighter-than-air machine) can never be of any practical use anyhow, even if you can steer it. For war purposes it offers too large a target for the enemy. The risk of a motor stopping on a small aeroplane would be much healthier. For private promenading it would be too costly. And as for general transportation — not to be considered at all. The *Santos-Dumont V* requires 550 cubic meters of gas for one little man of 120 pounds, and even then the little man can not take on more luggage than his life and his nerve, with a fair chance of losing both before he gets back. Therefore, a balloon with the passenger list of a small transatlantic steamer would have to be some twenty times larger than Barnum's biggest tent, and the balloon house would cover a fair-sized city. Only the traveler with a million to spare could book a passage thereon, and all the other millionaires would go bankrupt financing such an enterprise. The gentlest breeze would prove a tempest for the fabulously stupendous gas bag, and the pressure under ordinary conditions would make a metal covering

absolutely necessary. On the other hand, the aeroplane — when found — may be of a size more in proportion to the carriers on sea and land, and by inclinations of its surface it need not fear a gale much more than does a ship.

In conclusion it seems that the *Santos-Dumont V* may be correctly rated as the last evolution from Madame de Montgolfier's crinoline skirt. It is the culmination of balloons lighter than air. It is the first to make a trip in a breeze and come back to a point indicated beforehand. In a word, it is steerable. Of course there remains room for improvement, but hardly for further evolution. In aeronautics all evolution from now on must begin from the bird and end in the aeroplane. And perhaps that will involve a new principle of mechanics. The genius who discovers it will be a colossus, beside whom the clever and daring craftsman who applied an automobile motor to an inflated spindle will be but the merest pigmy. The aeroplane, though, has not left the ground yet. But the *Santos-Dumont V* has. The neighbors have already made complaint. They protest against the early morning flights, when the popping of the motor a few yards over their roofs breaks in on their slumber. There you have a foretaste of the future.

NOTE BY THE EDITOR.

It has been both a surprise and a disappointment to Santos-Dumont that time has not brought him a rival. This he tells us himself in the lively book devoted to his achievements in the air. So, while waiting for someone to run races with him in the clouds, he resolved to build an aërostatic masterpiece for the mere pleasure of an occasional outing above the roofs and parks of Paris. This was his great "No. 9."

Upon the dirigibility of this creation, which was the sensation of the French capital throughout the years 1903 and 1904, Santos-Dumont bestowed special pains. Experience had taught him much, and he himself assures us that successful navigation of the air is as much a matter of experience as is successful navigation of the sea. There is no secret of dirigibility as there was once a secret of Bessemer steel. The steering of Santos-Dumont's No. 9 depends, as the steering of its predecessors depended, upon the twin essentials of propeller and rudder. Both remain, as before, at the stern. Two huge fans again form the screw of the vessel, while No. 9's rudder is operated by means of a wheel in the small basket in which Santos-Dumont sits. A turn of the wheel shifts the rudder and No. 9 turns. All this means, of course, that the shape of the cigar, while far less pronounced and even gravitating toward the shape of the egg, had still to be kept in mind as an essential of dirigi-

bility. Santos-Dumont himself can not to-day steer a round balloon. The propeller, as before, is controlled by means of the shaft. In a word, dirigibility is attained by modifying, to suit atmospherical conditions, the available factors in navigation.

The old difficulties and the old limitations are there, too. Should the gear cords break, there is an end to dirigibility. Nor is the dirigibility of a kind to bid defiance to tempestuous air currents. But the young inventor overcomes this last obstacle by not ascending too high. Santos-Dumont seeks no glory by fighting strong winds. It suffices for him that No. 9 obediently turns in reasonable weather when he makes his rudder ropes taut.

His dexterity with the guide rope, Santos-Dumont thinks, accounts for the brilliance of No. 9's career. The guide rope has been of the utmost importance to the dirigibility of every Santos-Dumont airship. We have already seen that by pulling the guide rope towards the centre of equilibrium, and, when necessary, by letting it out again, the axis of the cigar-shaped or oval balloon is inclined now skyward and now earthward. The impetus supplied by the fans at the stern sends the airship up or down. But the guide rope is the source of stability, the means of obviating those lurches and pitches which are to aërial navigation what seasickness is to ocean voyages. In a mere pleasure craft like No. 9, the guide rope ought to trail on the ground as much as possible — or in the water at sea. But any lack of skill on the part of the aëronaut, the least failure to steer properly at a critical moment, must inevitably moor his airship to a tree, a church spire or, it might be, a lamp post. Yet so sure of himself was Santos-Dumont, so steady had his nerve become, that with a guide rope some hundred and fifty feet or less in length he toured the boulevards and avenues of Paris with the ease of an expert automobilist. This was in 1903.

The sensation of it all was prodigious. He took regular airings — in the most literal sense possible — from his own front door to the great triumphal arch and thence to the Bois de Boulogne, the famous pleasure ground of the French metropolis. Making it a rule not to ascend much above the level of the higher roofs and trees, he remained perfectly visible to the crowds who noted his easy and measured progress from their windows or in the streets below. "Thus I guide-roped through the Avenue du Bois," remarks Santos-Dumont in his book. "Thus, some day, explorers will guide-rope to the North Pole."

Pretty little incidents marked this progress about the city. One day, the aërial explorer took it into his head to come down among a group of children at play.

"Is there anyone here would like to ascend with me?" he inquired.

A bright maid of seven was quick to respond. She was a little American girl. Away she went into the air. Under the supervision of Santos-Dumont, who made this promenade a brief one, she steered with ease. That miss will make a perfect aëronaut one of these days, thinks her Brazilian tutor, should her talents be directed in maturer years, to such a field of endeavor. And on one memorable day a young lady full grown, described by Santos-Dumont as a most beautiful and bewitching Cuban,

pleaded for leave to ascend all by herself. The fact that he granted the request indicates, thinks Santos-Dumont, the extent of his confidence in No. 9. He gave three lessons in aërial navigation to this daring belle, who "guide-roped" alone for some miles, the poineer of her sex in the art of dirigible ballooning. "I will not pretend," says Santos-Dumont, "that no one followed the course of the trailing guide rope. But it is certain that no one touched it until the moment when, the promenade being ended at Bagatelle, the intrepid young 'navigatress' set foot on earth again."

The lightness, the compactness of this pleasure craft made such things possible. The balloon proper has a capacity of 1,100 cubic feet. The ballast carried does not at times exceed 65 pounds, but it can be increased, upon occasion, to some 140 pounds. The little three-horse-power motor weighs a trifle over 26 pounds. No. 9 was not built for speed, although it has carried its owner at the rate of fifteen to twenty miles an hour and more, notwithstanding the oval form towards which the cigar shape has evolved. The trailing of the guide rope on the ground has never led to misfortune. And, as has already been hinted, No. 9 never indulges in eagle flights. In fact, it seldom, when in town, goes far above a high roof. This, Santos-Dumont assures us, is sensible aërial navigation. It does away with the lurching and pitching which disturbed the course of his maiden flights before he had won any prizes. It avoids risk of falling. When the wind is unfavorable, its influence can be more readily overcome at a low altitude.

But there is one dire peril — that of "cold explosion"— which, with all his ingenuity, the young genius has not eliminated. There is still a possibility of conflagration. The petroleum reservoir (the gasoline tank) may in some unhappy moment of negligence catch fire from the motor by a "return" or sucking back of the flame. So careful has Santos-Dumont been in all his years of experiment that he has remained practically immune to this risk. Yet it did happen on one July day in 1903 that the very accident which he tries so hard to avoid nearly made an end of him and of No. 9 together. He was steering the aërial runabout across the Seine when the flame from the motor was drawn straight towards the gasoline tank. Seizing his Panama hat, the navigator of No. 9 fanned the flame out. The incident afforded him a text for some observations in his book. The insufficient working of the escape valves from the balloon, he tells us, might produce explosive complications. Then, should there be a cold explosion, the darting flame from the motor would be very apt to ignite the volume of mixed hydrogen and air all about. "But it would have no decisive influence on the result," notes the aëronaut reflectively. "The cold explosion itself would unquestionably be enough."

Another narrow escape from death came in the Mediterranean, on the occasion of a voyage from Monaco to Cape Martin and back. Santos-Dumont passed directly over the yacht of the Prince of Monaco, who attempted to seize the guide rope. The airship had descended quite near the surface of the sea, when the smokestack of the yacht began to emit red-hot sparks. As a single spark might have burned a hole in the bal-

loon, thus setting fire to the hydrogen, it seems a marvel that airship and owner were not then and there blown to atoms.

One peril, that of ascending too high, Santos-Dumont is determined to avoid. With the aid of shifting weights and propellers, his delicate craft could attain a great altitude easily. But her owner constantly declares that the proper place for an airship is at a low altitude. There is only useless risk, with no compensating advantage ordinarily, in swift vertical mounting to giddy heights.

The original purpose in the construction of No. 9, pleasure and amusement, was attained in ample measure, as appears from Santos-Dumont's account of his sensations as a passenger in his masterpiece. He was never seasick. In the airship there is no smell, none of that odor of paint, varnish and pitch, blended with the cooking, the vapors from the boilers and the stench of the smoke and hold which combine to afford a vivid impression of the atmosphere aboard an ocean liner. The very pitching is free from the shocks and the tumblings of a vessel at sea. Aboard the airship the motion is gentle and flowing, attributable, suspects Santos-Dumont, to the weaker resistance offered by atmospherical currents. The heaving is not so violent as that on the surface of the water. The succession of plunges and halts aboard a liner, occasioned by the unceasing rise and fall on the crest of waves, is absent. "The airship never leaves its element — the air — in which it only swings."

While on his aërial cruise above the Mediterranean, Santos-Dumont was struck by the ease with which he could discern objects moving beneath the surface of the water. It at once suggested itself that a submarine, lurking for prey, would be transparently visible to himself, although from the conning tower or bridge of a battleship no human eye could detect such an enemy's presence. "Thus, very oddly," writes our aërost in his book, "the airship of the twentieth century must be from the start the great foe of that other twentieth century marvel, the submarine." He has no doubt that victory must rest with the airship. The submarine can do it no damage. But the airship, twice as fast, can sail the atmosphere in obedience to the guide rope and signal the finding of the enemy under water to a neighboring squadron. Santos-Dumont would even undertake to destroy the submarine with arrows of dynamite.

This hint was too good to be lost upon the ministries of war and marine. For months past experiments have been conducted in profound secrecy under the supervision of Santos-Dumont. The great nation which is strongest in submarines promises to be the pioneer, too, in warfare directed from the clouds. The problem of keeping out of the range of guns is already solved. What other problems have been solved Santos-Dumont and the government of the third republic will not reveal. But in the next war between France and a European power — Santos-Dumont has excluded the American hemisphere by agreement — the world may witness a fulfillment of Tolstoi's dire prophecy that "cannon's flesh, as after cold weapons it submitted to bullets and meekly exposed itself to shells, bombs, far-reaching guns, mitrailleuse, mines, so it will also submit to bombs charged with suffocating gases scattered down upon it from balloons."

THE STORY OF RADIUM.

By CLEVELAND MOFFETT.

VERY well do I remember my first impression of M. Curie. It was in the rue Cuvier at the Sorbonne laboratories in Paris, where he was lecturing that day in the big amphitheatre, while I waited in an adjoining room among the air-pumps and electrical apparatus. Suddenly a door opened and there came a burst of applause, a long clapping of hands, and at the same moment a tall, pale man, slightly bent, walked slowly across the room.

On this occasion I simply made an appointment to see M. Curie the next morning at the École de Physique, but I profited by the opportunity to ask his assistant, M. Danne, some preliminary questions about radium. Was it true, *could* it be true, that this strange substance gives forth heat and light ceaselessly and is really an inexhaustible source of energy? Of course, I had read all this, but I wanted to hear it from the mouth of one who knew.

"It is quite true," said M. Danne, "that pure radium gives out light and heat without any waste or diminution that can be detected by our most delicate instruments. That is all we can say."

"Is the light that it gives a bright light?"

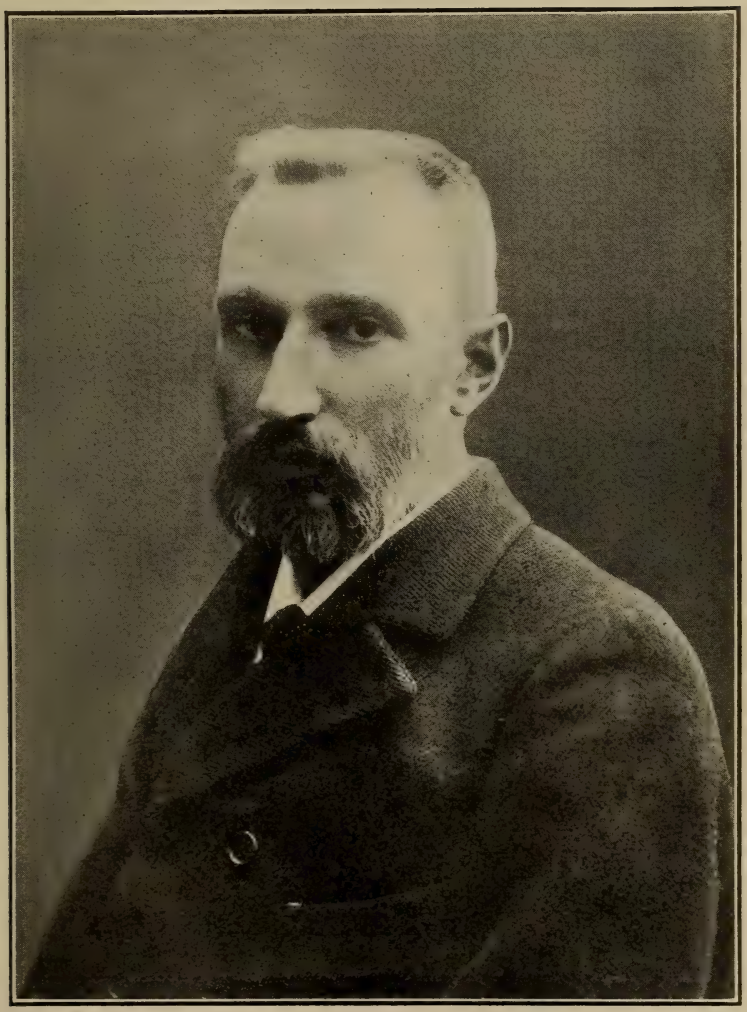
"Reasonably bright. M. Curie will show you."

"Can he explain it? Can any one explain it?"

"There are various theories, but they really explain very little."

M. Danne went on to indicate other properties of radium

* Radium, recently discovered by M. and Mme. Curie, of Paris, is one of the rarest of the seventy odd known elementary substances that compose our earth. It is worth about three thousand times its weight in pure gold. It looks like ordinary table salt. Thus far only a few ounces of radium have been taken from the earth and purified. The material for this article was furnished by M. Curie himself and his laboratory assistant, M. Danne.— THE EDITOR.



M. PIERRE CURIE.

The Discoverer of Radium.

that are scarcely less startling than these. Besides heat and light this strange metal gives out constantly three kinds of invisible rays that move with the velocity of light or thereabouts and that have separate and well-marked attributes. These rays may be helpful or harmful; they may destroy life or stimulate it. They are capable not only of shortening life or prolonging it, but of modifying existing forms of life; that is, of actually creating new species. Finally, by destroying bacteria, they may be used to cure disease, notably the dread lupus recently conquered by Finsen's lamps and now apparently conquered again by simpler means.

I listened in amazement; it was not one discovery but a dozen that we were contemplating.

"And — all this is M. Curie's discovery?"

"Radium is his discovery; that is, his and Madame Curie's. You cannot give one more credit than the other. They did it together."

He told me a little about Madame Curie, who, it appears, was a Polish student in the Latin Quarter, very poor, but possessed of rare talents. They say that her marriage with M. Curie was just such a union as *must* have produced some fine result. Without his scientific learning and vivid imagination it is doubtful if radium would ever have been dreamed of, and without her determination and patience against detail it is likely the dream would never have been realized.

The next day I found M. Curie in one of the rambling sheds of the École de Physique bending over a small porcelain dish, where a colorless liquid was simmering, perhaps half a teacupful, seven thousand francs' worth of radium in a fairly weak solution, and he watching it with concern, always fearful of some accident. He had lost nearly a decigramme (1.5 grains troy) of radium, he said, only a few weeks before in a curious way. He had placed some radium salts in a small tube, and this inside another tube, in which he created a vacuum. Then he began to heat both tubes over an electric furnace, when, suddenly, at about 2,000 degrees Fahrenheit, there came an explosion which shattered the tubes and scattered their precious contents. There was absolutely no explanation of this explosion; it was one of the tricks that radium is apt to play on you. Here his face lightened with quite a boyish smile.

M. Curie proceeded to explain what he was doing with the little dish; he was refining some radium dissolved in it; that is, freeing it from contaminating barium by repeated crystallization, this being the last and most delicate part of the process of obtaining the pure metal.

"We have our radium works outside of Paris," he said, "where the crude ore goes through its early stages of separation and where the radium is brought to an intensity of 2,000, as we express it. After that the process requires such care and involves so much risk of waste that we keep the precious stuff in our own hands and treat it ourselves, my wife and I, as I am doing now, to bring it to the higher intensities, 50,000, 200,000, 500,000, and finally, 1,500,000. What you see here is about 100,000. It will take many more crystallizations to bring it to the maximum."

"That is to the state of pure radium?"

"To the state of pure chloride of radium. You know the metal exists only as a chloride or bromide. It has never yet been isolated, although it easily might be."

"Why has it never been isolated?"

"Because it would not be stable; it would immediately be oxidized by the air and destroyed, as happens with sodium, whereas it remains permanent as a bromide or chloride and suffers no change."

M. Curie then explained that, among its many strange properties, radium has this one of rendering the air about it a better conductor of electricity, and the more it increases this conductivity of the air the more intense it is said to be. Now it has been known for several years that the metal uranium possesses properties similar to those of radium, only much less marked, consequently the unit of intensity chosen for a measuring instrument was the radio-activity of uranium, and when a given lot of radium is said to have a certain intensity, say, 2,000 or 500,000, it is understood that this radium renders the air 2,000 times or 500,000 times more conductive than an equal quantity of uranium would render it.

"Does radium change in appearance as it increases in intensity?" I asked.

"No, it keeps the form of small, white crystals, which may

be crushed into a white powder and which look like ordinary salt. See, here are some."

He took from the table drawer a small glass tube not much larger than a thick match. It was sealed at both ends and partly covered with a fold of lead. Inside the tube I could see a white powder.

"Why is the tube wrapped with lead?" I inquired.

"For the protection of those who handle it. Lead stops the harmful rays that would otherwise make trouble."

"Trouble?"

"Yes; you see the radium in this tube is very active; it has an intensity of 1,500,000, and if I were to lay it against your hand or any part of your body so," — he touched the bare tube to my hand — "and if I were to leave it there for a few minutes, you would certainly hear from it later."

"But I feel nothing."

"Of course not; neither did I feel anything when I touched some radium here," and pulling up his sleeve he showed me a forearm scarred and reddened from fresh-healed sores. "But you see what it did, and it was much less intense than this specimen."

He then mentioned an experience of his friend, Professor Becquerel, discoverer of the "Becquerel rays" of uranium, and in a way the parent-discovery of radium, since the latter discovery grew out of the former. It seems that Professor Becquerel, in journeying to London, carried in his waistcoat pocket a small tube of radium to be used in a lecture there. Nothing happened at the time, but about a fortnight later the professor observed that the skin under his pocket was beginning to redden and fall away, and finally a deep and painful sore formed there and remained for weeks before healing. A peculiar feature of these radium sores is that they do not appear for quite a time after exposure to the rays.

"Then radium is an element of destruction?" I remarked.

"Undoubtedly it has a power of destruction, but that power may be tempered or controlled, for instance, by this covering of lead. M. Danysz, at the Pasteur Institute, will give you the pathological facts better than I can."

This brought us back to physical facts, and I asked M. Curie

if the radium before us was at that moment giving out heat and light, for I could perceive neither.

"Of course it is," he replied. "I will take you into a dark room presently and let you see the light for yourself. As for the heat, a thermometer would show that this tube of radium is one and a half degrees Centigrade (2.7 degrees Fahrenheit) warmer than the surrounding air."

"Is it always that much warmer?"

"Always — as far as we know. I may put it more simply by saying that a given quantity of radium will melt its own weight of ice every hour."

"Forever?"

He smiled. "As far as we know — forever. Or again, that a given quantity of radium throws out as much heat in eighty hours as an equal weight of coal would throw out if burned to complete combustion in one hour."

"Suppose you had a considerable quantity of radium," I suggested, "say, twenty pounds, or a hundred pounds?"

"The law would be the same, whatever the quantity. If we had fifty kilos (110 pounds) of radium," he gave a little wondering cluck at the thought; "I say *if* we had fifty kilos of radium it would give out as much heat *continuously* as a stove would give out that burned ten kilos (twenty-two pounds) of coal every twenty-four hours, and was filled up fresh every day."

"And the radium would *never* cease to give out this heat and would *never* be consumed?"

"Never is a hard word, but one of our professors has calculated that a given quantity of radium, after throwing out heat as I have stated for a thousand million years, would have lost only one-millionth part of its bulk. Others think the loss might be greater, say, an ounce to a ton in ten thousand years; but in any case it is so infinitesimally small that we have no means of measuring it, and for practical purposes it does not exist."

After this M. Curie took me into a darkened room, where I *saw* quite plainly the light from the radium tube, a clear glow sufficient to read by if the tube were held near a printed page. And, of course, this was a very small quantity of radium, about six centigrammes (nine-tenths of a grain troy).

"We estimate," said he, "that a decigramme of radium will

illuminate a square decimeter (fifteen square inches) of surface sufficient for reading."

"And a kilogram (2.2 pounds) of radium?"

"A kilogram of radium would illuminate a room thirty feet square with a mild radiance. And the light would be much brighter if screens of sulphide of zinc were placed near the radium, for these are thrown by the metal into a brilliant phosphorescence."

"Then radium may be the light of the future?"

M. Curie shook his head. "I am afraid that we should pay rather dearly for such a light. There is first the money cost to be considered and then the likelihood that the people illuminated by radium would be also stricken with paralysis, blindness, and various nervous disorders. Possibly protective screens might be devised against these dangers, but it is too soon to think of that. For a long time to come the radium light will be only a laboratory wonder."

After we had been in the darkness for some time M. Curie wrapped the radium tube in thick paper and put it in my hand.

"Now," said he, "shut your eyes and press this against your right eyelid."

I did as he bade me and straightway had the sensation of a strange diffused light outside my eye. M. Curie assured me, however, that the light was not outside but *inside* the eye, the radium rays having the property of making the liquids of the eyeball self-luminous, a sort of internal phosphorescence being produced. He warned me that it would be dangerous to leave the radium against the eyelid very long, as a serious disturbance to the eyesight, or even blindness, might result.

Another experiment consisted in placing the radium against the bone at the side of the forehead, and even in this position, with the eyes closed, a light was perceptible, although fainter. Here the radium rays had acted upon the eyeball through the bones of the head.

"It is possible," said M. Curie, "that this property of radium may be utilized in certain diseases of the eye. Dr. Emile Javal, one of our distinguished physicians, who is blind himself, has given this matter particular attention, and he thinks that radium may offer a precious means of diagnosis in cases of cataract, by showing whether the retina is or is not intact, and whether an

operation will succeed. If a person blind from cataract can see the radium light as you have just seen it, then the eyesight of that person may be restored by removing the cataract. Otherwise it cannot be restored."

As we returned to the laboratory I remarked that the quantity of radium in the various tubes I had seen was very small.

"Of course it is small," he sighed; "there is very little radium in the world. I mean, very little that has been taken from the earth and purified."

"How much is there?"

He thought a moment. "We have about one gramme (one-third of an ounce) in France, Germany may have one gramme, America has less than one gramme, and the rest of the world may perhaps have half a gramme. Four grammes in all would be an outside estimate; you could heap it all in a tablespoon."

I suggested to M. Curie the possibility that some American philanthropist might be inspired on reading his words to help the new cause. And I remarked that great things could doubtless be accomplished with some substantial quantity of radium, say, a pound or two.

He gave me an amused look and asked if I had any idea what a pound or two of radium, say, a kilogram (two and one-fifth pounds), would cost?

"Why, no," said I; "no exact idea, but we have rich men in America, and——"

"A kilogram of radium would cost—" He figured rapidly on a sheet of paper. "With the very cheapest methods that we have of purifying the crude material, it would cost about ten million francs. Under existing conditions radium is worth about three thousand times its weight in pure gold."

"And yet there may be tons of it in the earth?"

M. Curie was not so sure of this. "It is doubtful," said he, "if there is very much radium in the earth, and what there is is so thinly scattered in the surrounding ore, mere traces of radium for tons of worthless rock, that the cost of extracting it is almost prohibitive. You will realize this when you visit our works at Ivry."

These works I visited the next day and found myself outside the walls of Paris, near the old Ivry Cemetery, where some unpretentious sheds serve for this important business of radium

MME. SKLODOWSKA CURIE,

Who Assisted her Husband in the Discovery of Radium.

extraction. One of the head men met me, and explained step by step how they obtain this strange and elusive metal. First he showed me a lumpy, reddish powder, sacks of it, brought from Bohemia by the ton, and constituting the raw material from which the radium is extracted. This powder is the refuse from uranium mines at Joachimsthal, that is what remains of the original uranite ore, pitchblende, after the uranium has been removed. For years this refuse was regarded as worthless, and was left to accumulate in heaps, tons of it, quite at the disposal of whoever chose to cart it away. Now that it is known to contain the rarest and most precious substance in the world, it goes without saying that the owners have begun to put a price on it.

My informant referred with proper pride to the difficulties that had confronted them when they started these radium works in 1901. It was a new problem in practical chemistry to bring together infinitesimal traces of a metal lost in tons of débris; it was like searching for specks of dust hidden in a sand heap, or for drops of perfume scattered in a river. Still, they went at it with good heart, for the end justified the effort. If it took a ton of uranite dust to yield as much radium as would half fill a doll's thimble, then the thing to do was to have many tons of this dust sent on from Bohemia and patiently to accumulate, after months of handling, various pinches of radium, a few centigrammes, then a few decigrammes, and finally, some day, who could tell, they might get as much as a gramme. This was a distant prospect, to be sure, yet with infinite pains, and all the resources of chemistry, it might be attained. Well, now they had attained it, and at this time, he said, some eight tons of uranite detritus had passed through the caldrons and great glass jars and muddy barrels of the Ivry establishment, had been boiled and filtered and decanted and crystallized, with much fuming of acids and the steady glow of furnaces; and out of it all, for the twenty-four months' effort, there had come just about a gramme of practically pure chloride of radium, enough white powder to fill a salt spoon.

Without going far into these refining processes, it may be noted that the radium exists here in combination with lead and chalk and silica and iron and various other things that must be gotten rid of one by one, in a series of reactions and operations

that are complicated and costly. For days the powder must simmer over a slow fire with water and soda; then it must be decanted into big barrels, where a sort of mud settles; then this mud must be washed and rewashed, and finally put back on the fire to simmer again with carbonate of soda. Then comes more decanting and the settling of more mud and the repeated washing of this, followed by treatment with hydro-chloric acid, which gives a colorless liquid, containing small quantities of radium.

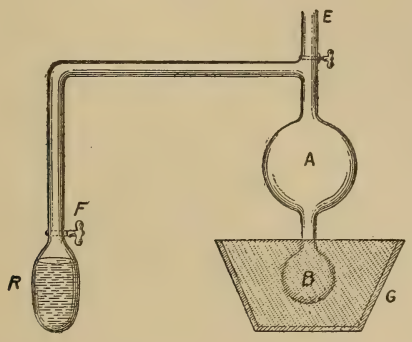
To isolate these small quantities from the rest is now the chemist's object, which is attained in a series of reactions and crystallizations that finally leave the precious chloride (or bromide) of radium much purified. In each crystallization the valuable part remains chiefly in the crystals, which become progressively richer in radium and smaller in bulk, until, finally, you have the product of six weeks' manipulation there at the bottom of a porcelain dish, no bigger than a saucer, some twenty-five grammes of white crystals, and these at so low an intensity (about 2,000) that the greater part will be refined away by M. Curie himself, as we have seen, in succeeding crystallizations, and at the very end there will be left only a few centigrammes (at 1,500,000); what would cover the point of a knife blade, to show for a ton or so of uranite powder and months of work.

When next I saw M. Curie he had just returned from London, where he had lectured before the Royal Institution. His hands were much peeled, and very sore from too much contact with radium, and for several days he had been unable to dress himself; but he took it good-naturedly, and proceeded to describe some of the experiments he had made before British scientists.

In order to demonstrate that radium throws off heat continually, he took two glass vessels, one containing a thermometer and a tube of radium, the other containing a thermometer and no radium. Both vessels were closed with cotton and it was presently seen that the thermometer in the vessel containing the radium registered constantly three degrees Centigrade (5.4 degrees Fahrenheit) higher than the thermometer which was not so influenced.

The most striking experiment presented by M. Curie in his London lecture was one devised by him to prove the existence

of radium emanations, a kind of gaseous product (quite different from the rays) which this extraordinary metal seems to throw off constantly as it throws off heat and light. These emanations may be regarded as an invisible vapor of radium, like water vapor, only infinitely more subtle, which settles upon all objects that it approaches and confers upon them, for a time at least, the mysterious properties of radium itself. Thus the yellow powder sulphide of zinc bursts into a brilliant glow under the stimulus of radium emanations, and to make it clear that this effect is due to the emanations and not to the rays, M.



Curie constructed an apparatus in which a glass tube R containing a solution of radium is connected with two glass bulbs A and B, containing sulphide of zinc.

The experiment is begun by exhausting the air from the two bulbs A and B, by means of air-pump connections through the tube E. The air is not exhausted, however, from the tube R, over which the stop-cock F is closed, and within which the emanations have been allowed to accumulate. The room is now darkened, and it is seen that so long as the stop-cock F remains closed there is no glow in the bulbs A and B, but as soon as the stop-cock F is opened both bulbs shine brilliantly, so that the light is plainly visible at a distance of several hundred yards. Now, obviously, if this effect were due to the radium rays, it would be produced whether the stop-cock F were open or closed, since the radium rays pass freely through glass and need not follow the tube S in order to reach the bulbs A and B. It is, therefore, clear that the sudden light in the bulbs is

due to the passage of *something* out of the tube R, and through the tube S, that *something* being kept back by the glass of the bulb R until the stop-cock F is opened. So we conclude that the emanations of radium *cannot* pass through glass, and are a manifestation quite distinct from the rays of radium, which *can* pass through but do not influence the sulphide of zinc.

This point having been established, M. Curie proceeded to the most sensational part of his demonstration, by closing the stop-cock F and then placing the lower bulb B, still radiant, in a vessel G containing liquid air, the result being that the light in the bulb B gradually grew stronger while the light in the bulb A diminished, until, presently, *all* the light seemed concentrated in B and gone from A, the conclusion being that the intense cold of liquid air had produced some change in the emanations, had possibly reduced them from a gas to a liquid, thus withdrawing them from A to B and checking the one glow while increasing the other.

In talking with Sir William Crookes, M. Curie was interested to learn that the English scientist had just devised a curious little instrument which he has named the spinthariscope and which allows one to actually *see* the emanations from radium and to realize as never before the extraordinary atomic disintegration that is going on ceaselessly in this strange metal. The spinthariscope is a small microscope that allows one to look at a tiny fragment of radium, about one-twentieth of a milligramme, supported on a little wire over a screen spread with sulphide of zinc.

The experiment must be made in a darkened room after the eye has gradually acquired its greatest sensitiveness to light. To the eye thus sensitive and looking intently through the lenses the screen appears like a heaven of flashing meteors among which stars shine forth suddenly and die away. Near the central radium speck the fire shower is most brilliant, while towards the rim of the circle it grows fainter. And this goes on continuously as the metal throws off its emanations; these myriad bursting blazing stars *are* the emanations, at least we may assume it, and become visible as the scattered radium dust or radium vapor impinges speck by speck upon the screen which, for each tiny fragment, flashes back a responsive phosphorescence. M. Curie spoke of this vision, that was really con-

tained within the area of a two-cent piece, as one of the most beautiful and impressive he had ever witnessed; it was as if he had been allowed to assist at the birth of a universe — or at the death of a molecule.

Dwelling upon the extreme attenuation of these radium emanations, M. Curie mentioned a recent experiment, in which he had used a platinum box pierced by two holes so extremely small that the box would retain a vacuum, yet not small enough to resist the passage of radium emanations.

In view of the extreme rarity and costliness of radium, it is evident that its emanations may be put to many important uses in and out of the laboratory, since they bestow upon indifferent objects — a plate, a piece of iron, an old shoe, anything — the very properties of radium itself. Thus a scientist or a doctor unable to procure the metal radium may easily experiment with a bit of wood or glass rendered radio-active, that is, charged by radium emanations, and capable of replacing the original metal as long as the charge keeps its potency. This period has been determined by the Curies after observations extending over weeks and months, and applied to all sorts of substances, copper, aluminum, lead, rubber, wax, celluloid, paraffin, not less than fifty in all, the resulting conclusions being formulated in a precise law as follows:

(1) All substances may be rendered radio-active through the influence of radium emanations.

(2) Substances thus influenced retain their induced radio-activity very much longer when guarded in a small enclosure through which the emanations cannot pass (say a sealed glass tube) than when not so guarded. In the former case their radio-activity diminishes one-half every four days. In the latter case it diminishes one-half every twenty-eight minutes.

I must pass rapidly over various other wonders of radium that M. Curie laid before me in subsequent conversations. There is matter here for a book, not a magazine article, and new matter is accumulating every week as the outcome of new investigations. Even in the chemistry of radium, which is practically an unexplored field, owing to the scarcity and costliness of the metal, there are various facts to be noted, as these: that radium changes the color of phosphorus from yellow to red; that radium rays increase the production of ozone in certain cases; that a

small quantity of radium dissolved in water throws off hydrogen constantly by causing a disintegration of the water, the oxygen released being absorbed in some unknown molecular combination. Also that a solution of radium gives a violet or brownish tint to a glass vessel containing it, this tint being permanent, unless the glass be heated red-hot. Here, by the way, is an application of importance in the arts, for radium may thus be used to modify the colors of glass and crystals, possibly of gems. It is furthermore established that radium offers a ready means of distinguishing real from imitation diamonds, since it causes the real stones to burst into a brilliant phosphorescence when brought near them in a darkened room, while it has scarcely any such effect upon false stones. M. Curie made this experiment recently at a reception in Lille, to the great delight of the guests.

In concluding the physical and chemical side of my subject, I must not fail to point out this singular fact: that a given quantity of radium, no matter how intense, may be shorn of its power to emit heat and light and of its other properties, indeed, may be rendered quite inert, at least for the time, either by submitting it (in solid form) to a prolonged heating at about 1,000 degrees Centigrade, or by keeping it for a number of hours in a vacuum. Why this treatment should effect such a change is not understood, or why the radium thus despoiled should recover its full energy by the gradual lapse of time, say, two or three months. These must be numbered among the many mysteries of the subject.

Coming now to what may be the most important properties of radium, that is, those which influence animal life, we may follow M. Curie's advice and visit the Pasteur Institute, where for some months now a remarkable series of radium tests have been in progress. In the second courtyard at the left, there where the hydrophobia dogs are always yelping, we shall find M. Danysz clad in his laboratory blouse and ready to explain, as far as he is able, the extraordinary effects of radium upon rabbits, guinea pigs, mice, and other small creatures that are exposed to the rays of this strange metal. One may say briefly that these effects have usually been destructive, the animals treated have nearly always died, but there is much in the manner of their death that merits our attention, since here seems to lie

a promise of new knowledge touching the very mysteries of death and of life.

Glancing rapidly over these experiments, it is at once apparent that radium has formidable powers of destruction, and can by its mere presence annihilate animal life or plant life. Here is one instance among many: On May 13, 1903, a little chloride of radium (five centigrammes) was suspended over the cage of eight white mice, two parent mice and six little ones, and was left there for three days and then removed. The mice continued to eat and run about as usual until May 16, when the little ones began to lose the fur on their backs. On the 19th their backs were quite bare of fur, although their heads remained covered, which gave them the appearance of little white lions. On the 21st the little ones became blind, although they continued to eat well. On the 23d one of the little ones died. On the 24th three died. On the 25th the remaining two died. On the 5th of June both the parent mice became blind. On the 28th both the parent mice died. This was the work of a few grains of radium in a tiny glass tube.

In another case two full-grown mice were exposed continuously to the same quantity (five centigrammes) of radium for ten days. For nine days they remained perfectly well, although they showed fear, but on the tenth day they died *without losing their fur*. This experiment was repeated with another pair of mice under the same conditions, except that the radium used was only half as intense, and in this case the mice died in twenty-two days and twenty-six days, respectively, and on the twentieth day they began to lose their fur. M. Danysz draws important conclusions touching the nature of the rays from the fact that the mice did or did not lose their fur.

Similar experiments were made upon other animals under varying conditions, the result being almost invariably death after a longer or shorter time, according to the animals' resistance. Rabbits were killed, guinea pigs were killed, embryo chickens exposed to radium rays during incubation (some on the first day, some on the tenth, some on the last day) were all killed, plants were killed, and M. Danysz is convinced that all animals, probably all forms of life, would succumb to the destructive force of radium if employed in sufficient quantities.

"I have no doubt," said he, "that a kilogram of radium would

be sufficient to destroy the population of Paris, granting that they came within its influence. Men and women would be killed just as these mice were killed. They would feel nothing during their exposure to the radium nor realize that they were in any danger. And weeks would pass after their exposure before anything would happen. Then gradually the skin would begin to peel off, and their bodies would become one great sore. Then they would become blind. Then they would die from paralysis and congestion of the spinal cord."

Despite this rather gloomy prospect, certain experiments at the Pasteur Institute may encourage us to believe that, for all its menace of destruction, radium is destined to bring substantial benefits to suffering humankind. The substance of these favorable experiments is that while animal life may undoubtedly suffer great harm from radium when used in excess or wrongly used (the same is true of strychnine), it may also derive immense good from radium when used within proper bounds, these to be set when we have gained a fuller knowledge of the subject. Meantime it is worthy of note that some of M. Danysz's animals, when exposed to the radium for a short time, or to radium of lower intensity, or to radium at a greater distance, have not perished, but have seemed to thrive under the treatment. A rabbit, for instance, underwent this attenuated radium treatment, with the result that its fur, instead of falling off, grew more abundantly.

But the most startling experiment performed thus far at the Pasteur Institute is one undertaken by M. Danysz, February 3, 1903, when he placed three or four dozen little worms that live in flour, the larvæ *Ephestia kuehniella,* in a glass flask, where they were exposed for a few hours to the rays of radium. He placed a like number of larvæ in a control flask, where there was no radium, and he left enough flour in each flask for the larvæ to live upon. After several weeks it was found that most of the larvæ in the radium flask had been killed, but that a few of them had escaped the destructive action of the rays by crawling away to distant corners of the flask, where they were still living. But *they were living as larvæ, not as moths,* whereas in the natural course they should have become moths long before, as was seen by the control flask, where the larvæ had all changed into moths, and these had hatched their eggs into other larvæ

and these had produced other moths. All of which made it clear that the radium rays had arrested the development of these little worms.

More weeks passed and still three or four of the larvæ lived, and four full months after the original exposure I saw a larva alive and wriggling while its contemporary larvæ in the other jar had long since passed away as aged moths, leaving generations of moths' eggs and larvæ to witness this miracle, for here was a larva, venerable among his kind, a patriarch *Ephestia kuehniella,* that had actually lived through *three times the span of life accorded to his fellows* and that still showed no sign of changing into a moth. It was very much as if a young man of twenty-one should keep the appearance of twenty-one for two hundred and fifty years!

Not less remarkable than these are some recent experiments made by M. Bohn at the biological laboratories of the Sorbonne, his conclusions being that radium may so far modify various lower forms of life as to actually produce "monsters," abnormal deviations from the original type of the species. Thus tadpole monsters have been formed from tadpoles exposed four days after birth to radium rays. Some of these monsters lived for twenty-three days, and would doubtless have lived longer had they been exposed to the rays for a shorter time. No changes occur in the tadpoles treated except at the transition points of growth, as on the eighth day, when the breathing tentacles are covered by gills in the normal tadpole, but are not so covered in the monsters formed after radium treatment. These monsters take on a new form, with an increasing atrophy of the tail and a curious wrinkling of the tissues back of the head; in fact, they may be said to develop a new breathing apparatus, quite different from that of ordinary tadpoles.

M. Bohn has obtained similar results with eggs of the toad and eggs of the sea-urchin, monsters resulting in both cases and continuing to live for a number of days or weeks after exposure to the radium. Furthermore, he has been able to accomplish with radium what Professor Loeb did with saline solutions; that is, to cause the growth of unfecundated eggs of the sea-urchin, and to advance these through several stages of their development. In other words, he has used radium *to create*

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life where there would have been no life but for this strange stimulation.

M. Bohn assured me of his conviction that we may in the future be able to produce new species of insects, moths, butterflies, perhaps birds and fishes, by simply treating the eggs with radium rays, the result being that interesting changes will be effected in the coloring and adornment. He also believes that with greater quantites of radium at our disposal and a fuller understanding of its properties, it may be possible to produce new species among larger creatures, mice, rabbits, guinea pigs, etc. It is merely a question of degree, for if new types can be produced in one species why may they not be produced in another?

It remains to mention certain important services that radium may render in the cure of bodily ills, notably of lupus and other skin diseases. Here is a great new field full of promise, yet one that must be considered with guarded affirmation, lest false hopes be aroused. It is too soon as yet to say more than this, that distinguished doctors speak with confidence of excellent results that may be looked for from the radium treatment. Dr. Danlos, for instance, has used the radium rays on lupus patients at the St. Louis Hospital in Paris for over a year, and in several cases has accomplished apparent cures. The radium used is enclosed between two small disks of copper and aluminum, the whole being about the size of a silver dollar. The aluminum disk, which is very thin, is pressed against the affected part and left there for fifteen minutes; that is all there is to the treatment, except cleansing, bandaging, etc. Day after day, for weeks or months, this contact with the disk is continued, and after a period of irritation the sores heal, leaving healthy, white scars. Some patients thus treated have gone for months without a relapse, but it is too soon to declare the cures absolute. They *look like* absolute cures, that is all Dr. Danlos will say, and if time proves that they *are* absolute cures, then radium will do for lupus patients all that Finsen's lamps do and will do it more quickly, more simply, and with no cumbersome and costly apparatus. It may be objected that radium also is costly, but the answer is that radium will probably become cheaper as the supply increases and as the processes of extracting it are perfected. Furthermore, the effects of radium may be obtained,

as already stated, by the use of indifferent bodies rendered radio-active, so that lupus patients may be treated with a piece of wood or a piece of glass possessed for the moment of the virtues of radium. And certain kinds of cancer may be similarly treated; indeed, a London physician has already reported a case of cancer cured by radium.

These are possibilities, *not* certainties, and there are others. It appears that radium has a bactericidal action in certain cases, and it would therefore seem reasonable that air rendered radio-active may benefit sufferers from lung troubles if breathed into the lungs, or that water rendered radio-active may benefit sufferers from stomach troubles if taken into the stomach. It goes without saying that in all these cases the use of radium must be attended with extreme precautions, so that harmful effects may be avoided.

Just as I was leaving Paris I learned of an interesting and significant new fact about radium, one that greatly impressed M. Curie, namely, that the air from deep borings in the earth is found to be radio-active, and that the waters from mineral springs are radio-active. This would seem to indicate the presence of radium in the earth in considerable quantities, and that would mean more abundant and cheaper radium in the not distant future. One of the things to be hoped for now is the discovery of a single simple reaction by which radium may be easily separated from the dross that contains it, and any day the chemists may put their hands on such a reaction.

And then — well, it is best to avoid sweeping statements, but there is certainly reason to believe that we are entering upon a domain of new, strange knowledge and drawing near to some of nature's most hallowed secrets.

ABSOLUTE COLD.

By HENRY DESMAREST.

WHEN a body loses its heat, it cools, in a relative sense, since it can be cold only by comparison with a warmer body.

Diminution of heat transforms all bodies, profoundly modifying their physical and chemical properties. The nature of heat is still unknown, as is the nature of light and of electricity. As yet, we are restricted to more or less ingenious hypotheses.

If we could extract from a body all the heat that it contains, we should attain what it is agreed to call absolute zero. But this experiment has not yet been made, notwithstanding the most recent researches into liquefied gas.*

In nature, in the normal atmospheric air that we breathe, in which we evolve, cold is never very intense, and is singularly removed from absolute zero. Nevertheless, between the extreme temperatures observed in tropical climates and in polar zones, it is possible to establish a difference of about 120 degrees Centigrade. This is prodigious if we reflect that our organism, which is so delicate, can withstand this variation in calorific intensity, provided, of course, that it be graduated thereto, for it is doubtful if any human being could pass with impunity from a temperature of +55 degrees, observed in Africa, to —65 degrees, registered in boreal America.†

At a height of some miles, the atmosphere is singularly cold, and the layer of warm air immediately in contact with the

* While waiting for the attainment of absolute zero, physicists fix it conventionally at 273 degrees Centigrade, that is to say, 273 degrees below melting ice, applying to the lowest temperatures the law of the dilatation of gases, whose co-efficient is almost without variation 1/273 at accessible temperatures. In fact, if this law were rigorously true, gas would have no volume under any pressure or no pressure whatever the volume at — 273 degrees.

† In a Centigrade temperature, the minus sign (—) always denotes "colder than freezing" Fahrenheit temperature. The temperature of

ground is but a thin film in comparison with the surface of the earth. Since the international organization of the service of balloon tests, it has been possible to establish, in a very precise fashion, the difference that exists between the temperature of the ground and the temperature of the upper atmosphere. Thus, in April, 1903, France, Germany, Russia, Austria and the United States co-operated in meteorological observations having for their object to determine the temperature at lofty altitudes. By the aid of balloons equipped with registering apparatus, the following temperatures were ascertained. At Trappes, at an altitude of 8,550 metres * the minimum temperature was —47 degrees (6.8 at departure). At Itteville (Paris) an ascension made at evening gave the very low temperature of —54 degrees at 9,650 meters (8 at departure), or 62 degrees difference for nine kilometers and a half. At Strasburg the balloon rose to a height of 10,000 meters. The minimum temperature observed was —44.4 degrees (5.7 upon departure at five o'clock in the morning). At Berlin, at a height of 8,380 meters the tem-

+ 55 degrees Centigrade, observed in Africa, would be one of 131 degrees Fahrenheit. The following table gives the comparative scale of the two thermometers:

Centigrade, 100°.	Fahrenheit, 212°.		Centigrade, 100°.	Fahrenheit, 212°.	
		Water Boils at Sea-Level.			
95	203		15.3	60	Temperate.
90	194		12.8	55	
85	185		10	50	
78.9	174		7.2	45	
75	167	Alcohol Boils.	5	41	
70	158		1.7	35	
65	149		0	32	
60	140		— 1.1	30	Water Freezes.
55	131		— 5	23	
52.8	127	Tallow Melts.	— 6.7	20	
50	122		—10	14	Zero Fahr.
45	113		—12.2	10	
42.2	108		—15	5	
40	104		—17.8	0	
36.7	98	Blood Heat.	—20	— 4	
35	95		—25	—13	
32.2	90		—30	—22	
30	86		—35	—31	
26.7	80		—40	—40	
25	77				
20	68				

* A metre is about a yard. A kilometre is about half a mile.

perature was —42 degrees (2 at departure). Two hours earlier, at 4.57 a. m., a balloon registered a temperature of 47.8 degrees at a height of 8,670 meters. At Blue Hill (U. S.), a flying kite went up 3,067 meters, the temperature recorded being —6.2 degrees. The temperature recorded at the observatory at the same time was 8.1 degrees.

In the polar regions it is not unusual to record quite low temperatures during the winter season.

The average temperatures observed aboard the *Fram,* from 1893 to 1896 were —18, —20.6, —18.1, in Lady Franklin Bay, from 1881 to 1883; —20.4, —19.3 in Floberg Beach from 1875 to 1876, which is moderate. But in Symmons's Meteorological Magazine, Mr. Hugh Robert Will has published a note upon the meteorological observations made by Mr. Charles Royds, meteorologist of the English Antarctic expedition aboard the *Discovery,* in lat. 77° 49′ S., long. 166° E., twenty-one miles from the volcano Erebus, in which we find registered a minimum of 38, 39, 43.8 degrees below zero (Fahrenheit).

It will be seen that the circumpolar regions have no occasion to envy the temperatures of the upper atmosphere. In our temperate regions the minimum temperatures seldom exceed —25 degrees. The lowest natural temperatures, produced, that is to say, by meteorological phenomena, are extremely high if compared with those obtained by the rapid evaporation of liquefied gases which sensibly approach absolute zero, or —273 degrees.

It is known that if an evaporating liquid does not receive a quantity of heat equivalent to that which becomes latent, the temperature immediately drops, the more considerably as the evaporation is the more rapid. Everyone is acquainted with Leslie's classical experiment: the freezing of evaporated water in the vacuum of a pneumatic bell, the vapors produced being absorbed by a very hygrometric body, such as sulphuric acid, for the purpose of maintaining the vacuum — the vapor of water (steam), even at a very low temperature, having still a very appreciable tension. Upon this phenomenon was based Carre's little ice machine, of which to-day there exist as many models as there are makers. If we operate with liquids more volatile than water we obtain a more considerable lowering and it is thus, from fall to fall, that we attain the liquefaction of all gases formerly considered permanent.

First of all, Faraday, with the aid of very rudimentary processes, made methodical researches into the liquefaction of gases. "In one of the branches of a V-shaped tube of small dimensions and fastened to the lamp, Faraday placed substances capable of giving, by the action of heat or by chemical reaction, a great volume of gas for liquefaction; the latter, thus enclosed in a small space, became compressed and liquefied in the other branch, which had previously been cooled. The sulphuric and carbonic anhydrides, sulphuric hydrogen, chlorhydric acid and others were thus liquefied by Faraday in 1823."

For the first time, in 1834, Thilorier liquefied carbonic-acid gas in bulk. By quickly opening to the free air the receiver containing the liquefied gas, he beheld the liquid solidify itself into a kind of snow which gave a reduction of —79 degrees. Faraday, in 1845, made use of this snow as a refrigerant. By mixing it with ether and evaporating it in a vacuum he obtained a temperature of —110 degrees, which, with a pressure of fifty atmospheres, permitted him to liquefy "ethylene, the fluoboric and fluosilicic acids, phosphorate hydrogen and arsenicated hydrogen." Hydrogen, oxygen, azote, bioxide of azote, oxide of carbon and formen could not then be liquefied and they were called permanent gases. In 1861, Andrews tried to liquefy the permanent gases by subjecting them to great pressures and chilling them like Faraday, but this process yielded no result whatever.

Then, by a series of experiments, which it would require too much space to recount here, Andrews showed that above a certain temperature, styled critical temperature, varying for every substance, gases can not assume liquid form, whatever be the pressure to which they are subjected. "From that time was explained the failure of efforts upon gases called permanent. The mixture of carbonic snow and ether had not furnished a temperature sufficiently low to determine liquefaction. The efforts of investigators thereafter were directed to methods of cooling." Let us note here that the critical temperature of carbonic acid is 31 degrees above zero, that of acetylene 37 degrees, that of chlorine 140 degrees, finally, that of sulphuric acid is 155 degrees. These critical temperatures are, therefore, higher than the temperatures of our climates. "Under ordinary circumstances, these gases are thus below their critical temperatures. It is thus not surprising that at their first efforts the physicists of the last cen-

tury, the Faradays and the Thiloriers, had the satisfaction of seeing these gases liquefy upon the mere application of sufficient pressure."

Two modes of cooling have been employed. By the sudden expansion of a liquefied gas, a more considerable lowering of temperature was obtained. A gas suddenly expanded cooled at a temperature that might be rather low for liquefying it, notwithstanding the small pressure then afforded by the apparatus. By this automatic cooling, Cailletet, in 1877, liquefied permanent gases, except hydrogen. At the same period Pictet liquefied oxygen by another process. "Taking advantage of the cold

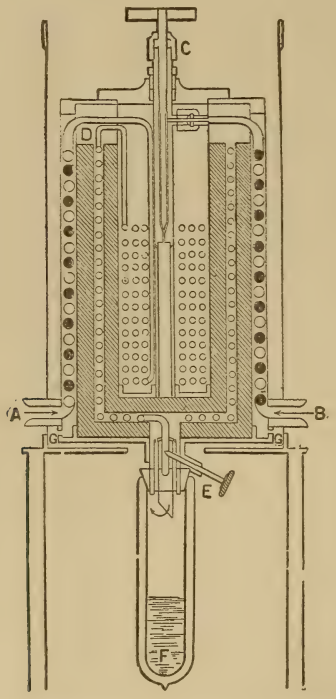


FIG. 1. SCHEME OF DEWAR'S APPARATUS.

A, Entrance for Air or Oxygen; B, Entrance for Carbonic Acid; C, Valve for the Expansion of Carbonic Acid; D, Worm for the recovery of the Cold; E, Valve for the Expansion of the Oxygen; F, Tube Containing Liquified Gas; G, Exit of the Carbonic Gas and Oxygen; o, Tubes for the Passage of the air; o, Tubes for the Passage of Carbonic Gas.

produced by the evaporation of liquefied sulphuric gas, Pictet liquefied and solidified carbonic-acid gas. The evaporation of the latter, effected in the vacuum of a pneumatic machine, supplied a temperature of —130 degrees, lower than the critical temperature of oxygen, which, from that time, could be liquefied. This is the process of cooling styled that of the cascade or successive falls of temperature." Vrobleffski and Olzeffski succeeded in obtaining gases in a liquid state in sufficient quantity to determine their ebullition temperature under atmospheric pressure. Air boils at —192.2 degrees; azote at —193 degrees; oxide of carbon at —186 degrees; marsh gas at —164 degrees.

It was James Dewar, an English physicist, who, in 1898, was the first to liquefy hydrogen. With the apparatus shown here (Fig. 1), he was able to liquefy and solidify very considerable quantities of atmospheric air to cool hydrogen at —205 degrees. Next compressing it under a pressure of 180 atmospheres he obtained stable liquid hydrogen, of which he determined the temperature of ebullition under atmospheric pressure.

If we imagine a special thermometer having a scale of which the zero is the conventional absolute zero, melting ice would

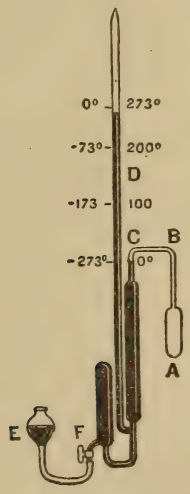


FIG. 2. LABORATORY THERMOMETER OF TRAVERS AND JACQUEROD FOR THE MEASUREMENT OF EXTREME COLD.

A, Ball of the Thermometer; B, Tube; C, Space with Point; D, Barometric Tube; E, Mercury Reservoir; F, Stopcock.

mark 273 degrees above absolute zero and boiling water 373 degrees.

We give here the scheme of a hydrogen thermometer of Dr. Jacquerod and Mr. Travers, of University College, London, for the measurement of very low temperatures. "Hydrogen fills the ball A, the tube B, and the little space C (Fig. 2). The mercury is always brought into contact, in the interior of C, with a little point of glass on which the reading is done. The pressure of the gas is measured by taking the vertical height, above the level C, of the mercury filling the tube D, in the upper part of which the barometric vacuum prevails. If a gas be maintained at a constant volume, but its temperature be modified, the pressure increases or decreases, for each degree it is heated or cooled, from 1/273 of the pressure supported by the gas to 0 degrees C. Therefore, if the pressure at 0 degrees C. is of 273 units, it will be of 373 units at the boiling point of water, and of 20.5 units at the boiling point of hydrogen."

Let us suppose the mercury is brought into contact with the point C before taking a measurement, in order to maintain the gas at a constant volume. The level of the point is marked 0° on the gas scale and 273° on the Centigrade scale, as if, at this hypothetical temperature, the gas no longer exerted any pressure at all. The level at which the mercury stops when the ball A is plunged into ice is marked 273° on the gas scale and 0° on the Centigrade scale. The intermediate series of temperatures is divided into 273 degrees.

"To measure the temperature of liquid air, we place an evacuated receiver, containing the liquid, under the ball of the thermometer and raise it slowly until the latter is completely immersed. Before this operation, and in order to prevent the mercury from penetrating into the ball, we remove a small quantity of the mercury from the apparatus by lowering the reservoir E and opening the stopcock F. When the ball is completely cooled, we again bring the mercury into contact with the point. The pressure of the gas in the thermometer, when the ball was immersed in the ice, was 273 units. It is now about 90 units, the temperatures of ice and of liquid air corresponding respectively to 273 degrees and 90 degrees on the gas scale. The temperature of liquid air is however variable, since oxygen boils at 90.1 degrees and azote at 77.5 degrees

on the hydrogen scale. Consequently, azote evaporates more rapidly. If we make liquid air boil in a vacuum, the temperature falls below —200 degrees C., or about 70 degrees on the gas scale."

By operating in the same way for liquid hydrogen, we find a temperature of 20 units on the hydrogen scale at a constant volume, which is equivalent to —253 degrees C.

With the object of separating newly discovered gases in the atmosphere, the neon of argon and of helium, Mr. W. Travers conceived the plan of separating gases by means of liquid hydrogen. The ball A (Fig. 3) is attached to a stopcock with

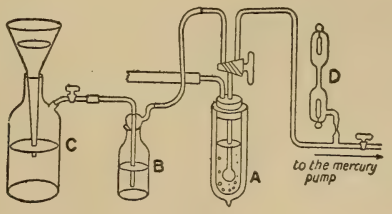


Fig. 3.

two outlets, which communicate on one side with a washing flask B, containing sulphuric acid, with a gasometer C, containing air, and on the other side with a Plücker tube D, in which a vacuum has been made by means of a mercury pump. We may surround the ball A with liquid air and by causing the latter to boil under reduced pressure, the liquid air can be condensed in the ball. When two liters of air have been condensed, we may close the stopcock and the receiver containing liquid hydrogen, prepared some moments previously. The liquid air now solidifies in the ball, but, as helium can not be liquefied at 13 degrees absolute and as neon has still a considerable pressure of vapor at the temperature of liquid hydrogen, these two substances remain in a gaseous state. If we turn the stopcock so as to place the ball in communication with the Plücker tube, the gases penetrate into the tube, which, traversed by an electric discharge, emits a pale rose gleam. Then the spectrum of neon and that of helium become visible."

According to the experiments of Mr. W. Travers, "the lowest temperature measured is that of the melting point of solid

hydrogen, that is, 14.1 degrees absolute. By causing solid hydrogen to evaporate under reduced pressure, it is possible to still further reduce the temperature, but probably not below 13 degrees absolute."

The attempt has been made without success to liquefy helium, this still very mysterious body, which, according to spectral analysis, seems to exist in great quantities in the solar atmosphere. The critical point of this gas, very rare in our atmosphere, ought to be in the neighborhood of ten degrees of absolute zero. This explains the difficulty we find in liquefying it, each degree towards absolute zero being very hard to obtain by our methods of investigation.

With helium liquefied, Mr. Travers thinks we can descend a few degrees still, to five degrees absolute, for instance, which will perhaps be the extreme limit of experiment, the absence of all heat seeming rather a theoretical conception than an experimental one.

We know now that all bodies without exception can be liquefied and volatilized by heat. Hence, all can be liquefied and solidified by subtraction from their heat. The specific heat of metals, their electrical resistance, their magnetic property even, are modified by cold. "In the absence of immediate interest," says M. Claude, "the theoretical interest of these facts is very great. They seem to verify, in fact, a bold hypothesis formulated by Ampere and according to which the resistance of metals to the electric current would appear only at the passage of intermoleculary spaces. At absolute zero, these vacuums no longer existing as a result of contraction, the electric resistance of pure metals ought to be nothing. This, indeed, is what, apart from an anomaly of a very disturbing kind in the temperature of liquid hydrogen, experience seems to confirm."

Nickel steel becomes magnetic at very low temperatures, while the magnetic properties of iron and of steel are slightly modified.. But the stability of magnetism becomes remarkable and a magnet remains permanent when it has been sufficiently cooled in liquid air.

From the biological point of view, a remarkable fact is that life very readily resists the absence of heat. Thus, microbes, for which the unit of measurement is the thousandth part of a millimetre, and which succumb at the temperature of boiling water,

can withstand, without sensibly losing their vitality, not only the temperature of liquid air, that is to say —190 degrees above zero, but also the operation of trituration. The little cells thus treated are then congealed into hard and friable masses. Of this immunity, M. d'Arsonval has given an ingenious explanation based upon the enormity of the osmotic pressure in microscopic bacterian cells. "Under these enormous pressures it is impossible for the water in the little cells to freeze even at —190 degrees, and the cells thus escape the disorganization to which they would otherwise be irremediably condemned."

From the hygienic point of view, it is thus a grave error, still very widespread, to believe that water in the frozen state is free from micro-organisms. The fermentation that water always retains in a more or less considerable quantity, once the ice is melted, resumes all its vitality. The same danger is present in the use of water obtained from the surfaces of rivers, ponds or public fountains for the manufacture of ice. The use of this ice for alimentary purposes is, moreover, forbidden in Paris by police regulations.

Certain bodies, such as eggs and paraffin, become phosphorescent in liquid air. On the subjects of phosphorescence and radiation, Sir William Crookes and James Dewar have undertaken a series of methodical studies of the influence of very low temperatures upon radium, the physical and chemical properties of which are scarcely beginning to be known.

It seems beyond doubt that cold must play a considerable part in the obscure or luminous radiations emitted by bodies and that very great progress will be made in physical astronomy when we fully know the part which the extra low temperatures of space may play in the luminous, electrical or magnetic emanations of celestial bodies.

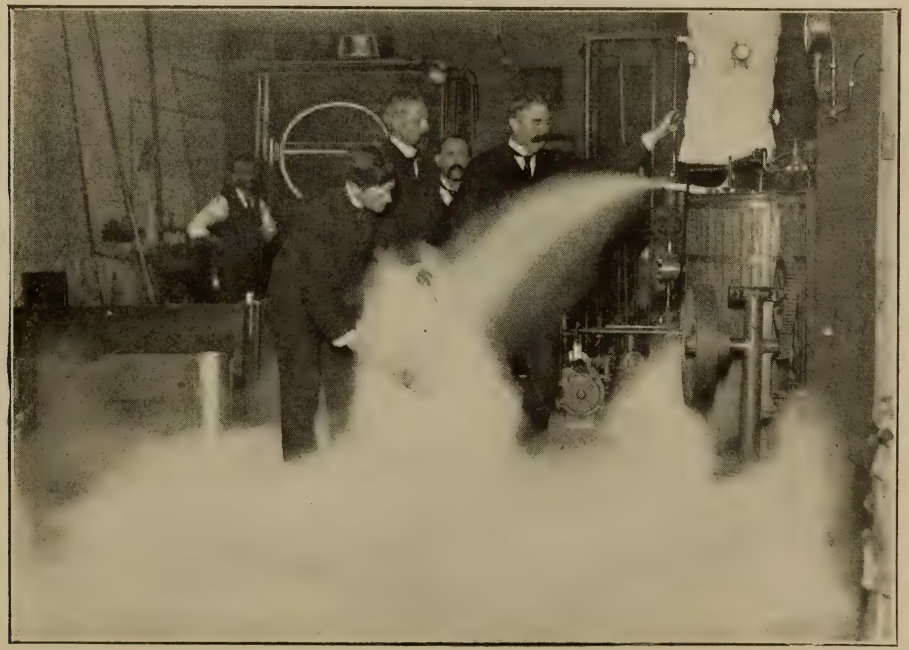
LIQUID AIR.

By RAY STANNARD BAKER.

LIQUID air is a clear, sparkling substance resembling water, but it is so cold that it boils on ice and freezes alcohol and mercury. Although fluid, it is not wet to the touch, but a drop of it on a man's hand burns like a white-hot iron. It may be dipped up and poured about like so much water, but if it is confined, it explodes more terribly than nitro-glycerine, and when left standing in the open air for a few minutes it vanishes in a cold gray mist, leaving behind only a bit of white frost.

Charles E. Tripler, of New York City, has invented a machine for producing this most marvelous of liquids in large quantities, and he has found many curious and wonderful uses to which it may be put. He predicts that it may sometimes rival electricity in the variety of its adaptations; he tells how it will be used to cool hospitals and hotels, cauterize wounds, drive the machinery of submarine boats, flying machines, and horseless carriages, furnish ammunition for military purposes, and perform many other mechanical wonders.

Until twenty years ago scientists believed that air was a permanent gas — that it never would be anything but a gas. They had tried compressing it under thousands of pounds of pressure to the square inch, they had tried heating it in the hottest furnaces, and cooling it to the greatest known depths of chemical cold, but it remained air — a gas. One day in 1878 Raoul Pictet submitted oxygen, of which air is largely composed, to enormous pressure combined with intense cold. The result was a few precious drops of a clear bluish liquid that bubbled violently for a few seconds and then passed away in a cold white mist. Pictet had proved that oxygen was not really a permanent gas, but merely the vapor of a mineral, as steam is the vapor of ice. Fifteen years later Olzewski, a Pole of Warsaw, succeeded in liquefying nitrogen, the other constituent of air.



MR. TRIPLER ALLOWING THE LIQUID AIR TO FLOW FROM THE LIQUEFIER.

On striking the warm outer atmosphere, part of the liquid air instantly vaporizes, and flows out upon the floor in thick, billowy clouds.

About the same time, Professor James Dewar, of England, exploring independently in the region of the North Pole of temperature, not only liquefied oxygen and nitrogen, but produced liquid air in some quantity and then actually froze it into mushy ice — air ice. The first ounce which he made cost more than $3,000. A little later he reduced the cost to $500 a pint, and the whole scientific world rang with the achievement.

When I visited Mr. Tripler's laboratory I saw five gallons of liquid air poured out like so much water. It was made at the rate of fifty gallons a day, and it cost, perhaps, twenty cents a gallon. Not long ago Mr. Tripler performed some of his experiments before a meeting of distinguished scientists at the American Museum of Natural History. It so happened that among those present was M. Pictet, the "father of liquid air." When he saw the prodigal way in which Mr. Tripler poured out the precious liquid, he rose solemnly and shook Mr. Tripler's hand. "It is a grand exhibition," he exclaimed in French; "the grandest exhibition I ever have seen."

The principle involved in air liquefaction is exceedingly simple, although its application has sorely puzzled more than one wise man. When air is compressed it gives out its heat. Any one who has inflated a bicycle tire has felt the pump grow warm under his hand. When the pressure is removed and the gas expands, it must take back from somewhere the heat which it gave out. That is, it must produce cold.

Professor Dewar applied this simple principle in all his experiments. He compressed nitrous oxide gas and ethylene gas, and by expanding them suddenly in a specially constructed apparatus he produced a degree of cold which liquefied air almost instantly.

But nitrous oxide and ethylene are exceedingly expensive and dangerous, so that the product which Professor Dewar drew off was worth more than its weight in gold.

At the earliest announcement of the liquefaction of air Mr. Tripler had seen, with the quick imagination of the inventor, its tremendous possibilities as a power-generator, and he began his experiments immediately. After futile attempts to utilize various gases for the production of the necessary cold, it suddenly occurred to Mr. Tripler that air also was a gas. Why not use it for producing cold?

"The idea was so foolishly simple that I could hardly bring myself to try it," he told me, "but I finally fitted up an apparatus, turned on my air and drew it out a liquid."

Mr. Tripler's work-room has more the appearance of a machine shop than a laboratory. It is big and airy, and filled with the busy litter of the inventor. The huge steam boiler and compressor engine in one end of the room strike one at first as oddly disproportionate in size to the other machinery. Apparently there is nothing for all this power — it is a seventy-five horse-power plant — to work upon; it is hard to realize that the engine is drawing its raw material from the very room in which we are walking and breathing. Indeed, the apparatus where the air is actually liquefied is nothing but a felt and canvas-covered tube about as large around as a small barrel and perhaps fifteen feet high. The lower end is set the height of a man's shoulders above the floor, and there is a little spout below, from which, upon opening a frosty valve, the liquid air may be seen bursting out through a cloud of icy mist. I asked the old engineer who has been with Mr. Tripler for years, what was inside this mysterious swathed tube.

"It's full of pipes," he said.

I asked Mr. Tripler the same question.

"Pipes," was his answer—"pipes and coils with especially constructed valves — that's all there is to it."

So I investigated the pipes. Two sets led back to the compressor engine, and Mr. Tripler explained that they both carried air under a pressure of about 2,500 pounds to the square inch. The heat caused by the compression had been removed by passing the pipes through coolers filled with running water, so that the air entered the liquefier at a temperature of about fifty degrees Fahrenheit.

"One of these pipes contains the air to be liquefied," explained Mr. Tripler; "the other carries the air which is to do the liquefying. By turning this valve at the bottom of the apparatus, I allow the air to escape through a small hole in the second pipe. It rushes out over the first pipe, expanding rapidly, and taking up heat. This process continues until such a degree of cold prevails in the first pipe that the air is liquefied and drips down into a small receptable at the bottom. Then all

I have to do is to turn a valve and the liquid air pours out, ready for use."

Mr. Tripler says that it takes only fifteen or twenty minutes to get liquid air after the compressor engine begins to run. Professor Dewar always lost ninety per cent. in drawing off his product; Mr. Tripler's loss is inappreciable.

Sometimes the cold in the liquefier becomes so intense that the liquid air actually freezes hard, stopping the pipes. Wonderful as it is to see ice that is made of air, it is not so wonderful as Mr. Tripler's story of the significance of this phenomenon. He tells how at some remote age in the future, all of the atmosphere which we now breathe will fall in drops of liquid, just such as he produces in his laboratory, and great lakes and oceans of air will form on the earth, much resembling the present lakes and oceans of water.

"When the earth grows so cold that the air is liquefied," said Mr. Tripler, "of course all the water on the earth will long ago have been frozen solid. Indeed, it will be as hard as rock crystal, and not unlike that substance in color and texture. After the air is all in the form of lakes or oceans, the cold will continue to increase until they in turn are frozen hard. After that the hydrogen, helium, and possibly some other very light gases, of which we may now have little knowledge, will fall in the form of rain, and then the world will be absolutely dead and inert, frozen as hard as the moon."

This entire process of the universe is typified in Mr. Tripler's laboratory, where every degree of temperature, from the heat of a steam boiler nearly down to the cold of interstellar space, can be produced at any time.

"When you come to think of it," says Mr. Tripler, "we're a good deal nearer the cold end of the thermometer than we are to the hot end. I suppose that once the earth had a temperature equal to that of the sun, say, 10,000 degrees Fahrenheit. It has fallen to an average of about sixty degrees in this latitude; that is, it has lost 9,940 degrees. We don't yet know just how cold the absolute cold really is — the final cold, the cold of interstellar space — but Professor Dewar thinks it is about 461 degrees below zero, Fahrenheit. If it is, we have only a matter of 521 degrees yet to lose, which is small compared with 9,940. Still, I don't think we have any cause to worry; it may take

a few billion years for the world to reach absolute cold."

Mr. Tripler handles his liquid air with a freedom that is awe-inspiring. He uses a battered saucepan in which to draw it out of the liquefier, and he keeps it in a double iron can, not unlike an ice-cream freezer, covering the top with a wad of coarse felt to keep out as much heat as possible.

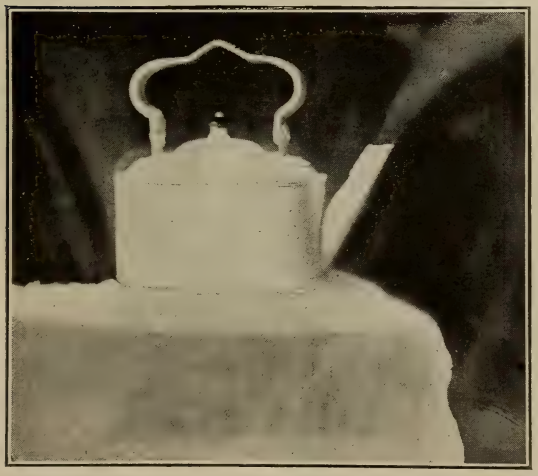
"You can handle liquid air with perfect safety," he said; "you can do almost anything with it that you can do with water, except to shut it up tight."

This is not at all surprising when one remembers that a single cubic foot of liquid air contains 748 cubic feet of air at ordinary pressure — a whole hall-bedroom full, reduced to the space of a large pail. Its desire to expand, therefore, is something quite irrepressible. But so long as it is left open it simmers contentedly for hours, finally disappearing whence it came. There being no way to confine liquid air in any considerable quantity, its transportation for long distances is therefore an unsolved problem, although Mr. Tripler has sent large cans of it to Boston, Washington and Philadelphia.

"It is my belief," comments Mr. Tripler, "that there will be little need of transporting it; it can be made quickly and cheaply anywhere on earth."

Liquid air has many curious properties. It is nearly as heavy as water and quite as clear and limpid, although when seen in the open air it is always muffled in the dense white mist of evaporation which wells up over the edge of the receptacle in which it stands and rolls out along the floor in beautiful billowy clouds. No other substance in the world, unless it be liquid hydrogen, is as cold as liquid air, and yet Mr. Tripler dips his hand fearlessly into a pail of liquid air, but he is careful to withdraw it instantly. The reason that it does not freeze him at once is the same that enables the workman to dip his hand into molten lead, the moisture of the human flesh forming a little cushion of vapor which keeps away for a second the effect of the cold or the heat. A few drops held in my hand for an instant felt exactly like a red-hot coal. It does not really burn, of course, but it kills, leaving a little red blister not unlike a burn. For this reason, one of its prospective uses will be for the purpose of cauterization in surgical cases. It is not only a good deal cheaper than the ordinary caustics, but is much more

AN ICICLE OF FROZEN ALCOHOL.



LIQUID AIR BOILING ON A BLOCK OF ICE.

Compared with liquid air, the temperature of which is 312° *below zero, ice at* 32° *F. is as hot as a furnace, and it produces the same effect on liquid air that a hot fire would on water. The teapot is covered with white frost: moisture congealed from the atmosphere.*

efficient, and its action can be absolutely controlled. Indeed, a well-known surgeon performed a difficult operation on a cancer case with liquid air furnished by Mr. Tripler, and reported the case to be absolutely cured.

It is a curious thing to see liquid air placed in a teapot boiling vigorously on a block of ice, but it must be remembered that ice is nearly as much warmer than liquid air as a stove is warmer than water, so that it makes liquid air boil just as the stove makes water boil. If this same teapot is placed over a gas flame, a thick coating of ice will at once collect on the bottom between the kettle and the blaze, and no amount of heat seems enough to melt it.

Alcohol freezes at so low a temperature — 202 degrees below zero — that it has been used in thermometers to register all degrees of cold. But it will not measure the fearful cold of liquid air. I saw a cup of liquid air poured into a tumbler partly filled with alcohol. Mr. Tripler stirred the mixture with a glass rod. It boiled violently for a few minutes and then the alcohol thickened up slowly until it looked like maple syrup; then it froze solid, and Mr. Tripler held it up in a long steaming icicle. Mercury is frozen in liquid air until it is as hard as granite. Mr. Tripler made a little pasteboard box the shape of a hammer-head, filled it with mercury, suspended a rod in it for a handle, and then placed it in a pan of liquid air. In a few minutes the mercury was frozen so solid that it could be used for driving nails into a hard-wood block. What would the scientists of twenty-five years ago have said if any one had predicted the use of a mercury hammer for driving nails?

Liquid air freezes other metals just as thoroughly as it freezes mercury. Iron and steel become as brittle as glass. A tin cup which has been filled with liquid air for a few minutes will, if dropped, shatter into a hundred little fragments like thin glass. Copper, gold, and all precious metals, on the other hand, are made more pliable, so that even a thick piece can be bent readily between the fingers.

Not long ago Mr. Tripler took a can of liquid air to the Harlem River, and poured it out on the water in order to see its effect. Small masses of it at once collected in little round balls on the surface of the river, and being so much colder than the water, they froze small cups or boats of ice, in which they

began floating about swiftly, bumping up against one another like so many lively water bugs, finally boiling away and disappearing, leaving the miniature ice boats quite still. If a small quantity of liquid air is placed in a tall jar of water, part of the liquid nitrogen, which is lighter than water, will evaporate first, then the liquid oxygen, which is slightly heavier than the water, will sink in beautiful silvery bubbles.

I saw an egg frozen in liquid air. It came out so hard that it took a sharp blow of the hammer to crack it, and the inside of it had the peculiar crystalline appearance of quartz — a kind of mineral egg. At one time in Boston, Mr. Tripler had some of his liquid air with him at a hotel, where he was explaining its wonders to a party of friends. The waiter served a fine beefsteak for dinner, and Mr. Tripler promptly dipped it into the liquid air and then returned it with some show of indignation to the chef. It was as hard as rock crystal and when dropped on the floor it shivered into a thousand pieces.

"The time is certainly coming," says Mr. Tripler, "when every great packing house, every market, every hospital, every hotel, and many private houses will have plants for making liquid air. The machinery is not expensive, it can be set up in a tenth part of the space occupied by an ammonia ice machine, and its product can be easily handled and placed where it is most needed. Ten years from now hotel guests will call for cool rooms in summer with as much certainty of getting them as they now call for warm rooms in winter.

"And think of what unspeakable value the liquid air will be in hospitals. In the first place, it is absolutely pure air; in the second place the proportion of oxygen is very large, so that it is vitalizing air. Why, it will not be necessary for the tired-out man of the future to make his usual summer trip to the mountains. He can have his ozone and his cool heights served to him in his room. Cold is always a disinfectant; some disease germs, like yellow fever, it kills outright. Think of the value of a 'cold ward' in a hospital, where the air could be kept absolutely fresh, and where nurses and friends could visit the patient without fear of infection!"

The property of liquid oxygen to promote rapid combustion will make it invaluable, Mr. Tripler thinks, for use as an explosive. A bit of oily waste, soaked in liquid air, was placed inside

HANGING FROM A BLOCK OF FROZEN MERCURY.

The mercury is poured into a paper mould having a screw-eye inserted in each end. The mould is then placed in a basin of liquid air, where the mercury is quickly frozen solid. Suspended in the manner shown, the mercury block will support several hundred pounds for half an hour.

of a small iron tube, open at both ends. This was laid inside of a larger and stronger pipe, also open at both ends. When the waste was ignited by a fuse, the explosion was so terrific that it not only blew the smaller tube to pieces, but it burst a great hole in the outer tube. Mr. Tripler thinks that by the proper mixture of liquid air with cotton, wool, glycerine, or any other hydrocarbon, an explosive of enormous power could be produced. And unlike dynamite or nitro-glycerine, it could be handled like so much sand, there being not the slightest danger of explosion from concussion, although, of course, it would have to be kept away from fire. It will take many careful experiments to ascertain the best method for making this new explosive, but think of the reward for its successful application! The expense of heavy ammunition and its difficult transportation and storage would be entirely done away with. No more would warships be loaded down with cumbersome explosives, and no more could there be terrible powder explosions on shipboard, because the ammunition could be made for the guns as it was needed, a plant on shipboard furnishing the necessary liquid air.

Liquid air, owing to the large amount of oxygen which it contains, will make steel burn violently. Mr. Tripler places a little of it in a tumbler made of ice, and then thrusts into it a steel spring having at the end a lighted match. The moment the steel strikes the liquid air it burns like a splinter of fat pine. This experiment shows a most astonishing range of temperature. Here is steel burning at 3,500 degrees above zero in an ice receptacle containing liquid air at 312 degrees below zero.

But all other uses of liquid air fade into insignificance when compared with the possibility of its utilization as power for running machinery, which is Mr. Tripler's chief object. I saw Mr. Tripler admit a quart or more of the liquid air into a small engine. A few seconds later the piston began to pump vigorously, driving the fly-wheel as if under a heavy head of steam. The liquid air had not been forced into the engine under pressure, and there was no perceptible heat under the boiler; indeed, the tube which passed for a boiler was soon shaggy with white frost. Yet the little engine stood there in the middle of the room, running apparently without motive power, making no noise and giving out no heat and no smoke, and producing no

ashes. And that is something that can be seen nowhere else in the world.

"If I can make little engines run by this power, why not big ones?" asks Mr. Tripler.

"And run them entirely with air?"

"Yes, with liquid air in place of the water now used in steam boilers, and the ordinary heat of the air instead of the coal under the boilers. Air is the cheapest material in the world, but we have only begun learning how to use it. We know a little about compressed and liquid air, but almost nothing about utilizing the heat of the air. Coal is only the sun's energy stored up. What I do is to use the sun's energy direct.

"It is really one of the simplest things in the world," Mr. Tripler continued, "when you understand it. In the case of a steam-engine you have water and coal. You must take heat enough out of the coal, and put it into the water to change the water into a gas — that is, steam. The expansion of this gas produces power. And the water will not give off any steam until it has reached the boiling point of 212 degrees Fahrenheit.

"Now steam bears the same relation to water that air does to liquid air. Air is a liquid at 312 degrees below zero — a degree of cold that we can hardly imagine. If you raise it above 312 degrees below zero, it boils, just as water boils above 212 degrees. Now, then, we live at a temperature averaging, say, seventy degrees above zero — about the present temperature of this room. In other words, we are 382 degrees warmer than liquid air. Therefore, compared with the cold of liquid air we are living in a furnace. A race of people who could live at 312 degrees below zero would shrivel up as quickly in this room as we would if we were shut up in a baking oven. Now then, you have liquid air — a liquid at 312 degrees below zero. You expose it to the heat of this furnace in which we live, and it boils instantly and throws off a vapor which expands and produces power. That's simple, isn't it?"

It did seem simple; and you remember with admiration that Mr. Tripler is the first man who ever ran an engine with liquid air, as he was also the first to invent a machine for making liquid air in quantities, a machine which has since been patented.

In some respects liquid air possesses a vast supremacy over steam. In the first place, it has about one hundred times the

expansive power of steam. In the second place, it begins to produce power the instant it is exposed to the atmosphere. In making steam, water has first to be raised to a temperature of 212 degrees Fahrenheit. That is, if the water as it enters the boiler has a temperature of 50 degrees, 162 degrees of heat must be put into it before it will yield a single pound of pressure. After that, every additional degree of heat produces one pound of pressure; whereas every degree of heat applied to liquid air gives about twenty pounds of pressure.

"Liquid air can be applied to any engine," says Mr. Tripler, "and used as easily and as safely as steam. You need no large boiler, no water, no coal, and you have no waste. The heat of the atmosphere, as I have said before, does all the work of expansion."

The advantages of compactness, and the ease with which liquid air can be made to produce power by the heat of the atmosphere, at once suggested its use in all kinds of motor vehicles, and a firm in Philadelphia is now making extensive experiments looking to its use. A satisfactory application may do away with the present huge, misshapen, machinery-laden automobiles, and make possible small, light, and inexpensive motors.

Mr. Tripler even predicts that by the agency of liquid air, practical aërial navigation can be assured. The problem which has hitherto defeated the purposes of aërial navigators has been the difficulty of producing a propelling machine sufficiently light and yet strong enough to keep the propeller in motion. Liquid air requires no boilers, no fuel, no smokestacks, and the machinery necessary to its use will be a mere feather's weight compared with the ordinary steam-engine.

Much has yet to be done before liquid air becomes the revolutionizing power of which Mr. Tripler has prophesied. It has many disadvantages as well as advantages, and it will undoubtedly take Mr. Tripler and other inventors many years to perfect the machines necessary for using it practically. It will probably be chiefly valuable in cases where a source of power must be produced at one place and used at another. This much, however, has been positively accomplished: A machine has been built which will make liquid air in large quantities at small expense, and an engine has been successfully run by liquid air. Other developments will undoubtedly come later.

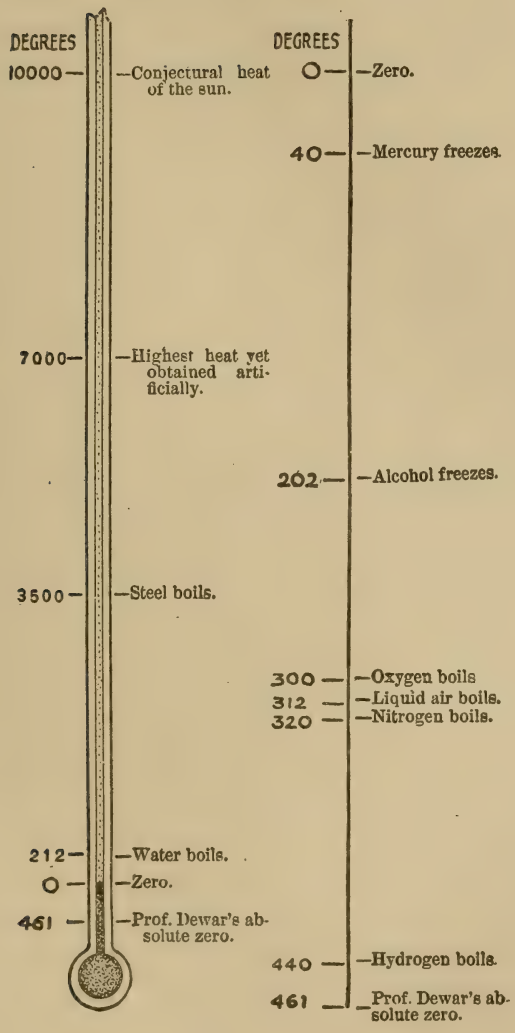
THE HOTTEST HEAT.

By RAY STANNARD BAKER.

NO feats of discovery, not even the search for the North Pole or Stanley's expeditions in the heart of Africa, present more points of fascinating interest than the attempts now being made by scientists to explore the extreme limits of temperature. We live in a very narrow zone in what may be called the great world of heat. The cut on the opposite page represents an imaginary thermometer showing a few of the important temperature points between the depths of the coldest cold and the heights of the hottest heat — a stretch of some 10,461 degrees. We exist in a narrow space, as you will see, varying from 100° or a little more above the zero point to a possible 50° below; that is, we can withstand these narrow extremes of temperature. If some terrible world catastrophe should raise the temperature of our summers or lower that of our winters by a very few degrees, human life would perish off the earth.

But though we live in such narrow limits, science has found ways of exploring the great heights of heat above us and of reaching and measuring the depths of cold below us, with the result of making many important and interesting discoveries.

I have written in a former chapter of that wonderful product of science, liquid air — air submitted to such a degree of cold that it ceases to be a gas and becomes a liquid. This change occurs at a temperature 312° below zero. Professor John Dewar, of England, who has made some of the most interesting of discoveries in the region of great cold, not only reached a temperature low enough to produce liquid air, but he succeeded in going on down until he could freeze this marvelous liquid into a solid — a sort of air ice. Not content even with this astonishing degree of cold, Professor Dewar continued his experiments until he could reduce hydrogen — that very light gas —


DEGREES
10000
Conjectural heat of the sun.
7000
Highest heat yet obtained artificially.
3500
Steel boils.
212
Water boils.
0
Zero.
461
Prof. Dewar's absolute zero.
DEGREES
0
Zero.
40
Mercury freezes.
202
Alcohol freezes.
300
Oxygen boils
312
Liquid air boils.
320
Nitrogen boils.
440
Hydrogen boils.
461
Prof. Dewar's absolute zero.

to a liquid at 440° below zero, and then, strange as it may seem, he also froze liquid hydrogen into a solid. From his experiments he finally concluded that the "absolute zero" — that is, the place where there is no heat — was at a point 461° below zero. And he has been able to produce a temperature, artificially, within a very few degrees of this utmost limit of cold.

Think what this absolute zero means. Heat, we know, like electricity and light, is a vibratory or wave motion in the ether. The greater the heat, the faster the vibrations. We think of all the substances around us as solids, liquids, and gases, but these are only comparative terms. A change of temperature changes the solid into the liquid, or the gas into the solid. Take water, for instance. In the ordinary temperature of summer it is a liquid, in winter it is a hard crystalline substance called ice; apply the heat of a stove and it becomes steam, a gas. So with all other substances. Air to us is an invisible gas, but if the earth should suddenly drop in temperature to 312° below zero all the air would fall in liquid drops like rain and fill the valleys of the earth with lakes and oceans. Still a little colder and these lakes and oceans would freeze into solids. Similarly, steel seems to us a very hard and solid substance, but apply enough heat and it boils like water, and finally, if the heat be increased, it becomes a gas.

Imagine, if you can, a condition in which all substances are solids; where the vibrations known as heat have been stilled to silence; where nothing lives or moves; where, indeed, there is an awful nothingness; and you can form an idea of the region of the coldest cold — in other words, the region where heat does not exist. Our frozen moon gives something of an idea of this condition, though probably, cold and barren as it is, the moon is still a good many degrees in temperature above the absolute zero.

Some of the methods of exploring these depths of cold are treated in the chapter on liquid air already referred to. Our interest here centers in the other extreme of temperature, where the heat vibrations are inconceivably rapid; where nearly all substances known to man become liquids and gases; where, in short, if the experimenter could go high enough, he could reach the awful degree of heat of the burning sun itself, estimated at over 10,000 degrees. It is in the work of exploring these re-

gions of great heat that such men as Moissan, Siemens, Faure, and others have made such remarkable discoveries, reaching temperatures as high as 7,000, or over twice the heat of boiling steel. Their accomplishments seem the more wonderful when we consider that a temperature of this degree burns up or vaporizes every known substance. How, then, could these men have made a furnace in which to produce this heat? Iron in such a heat would burn like paper, and so would brick and mortar. It seems inconceivable that even science should be able to produce a degree of heat capable of consuming the tools and everything else with which it is produced.

The heat vibrations at 7,000° are so intense that nickel and platinum, the most refractory, the most unmeltable of metals, burn like so much bee's-wax; the best fire-brick used in lining furnaces is consumed by it like lumps of rosin, leaving no trace behind. It works, in short, the most marvelous, the most incredible transformations in the substances of the earth.

Indeed, we have to remember that the earth itself was created in a condition of great heat — first a swirling, burning gas, something like the sun of to-day, gradually cooling, contracting, rounding, until we have our beautiful world, with its perfect balance of gases, liquids, solids, its splendid life. A dying volcano here and there gives faint evidence of the heat which once prevailed over all the earth.

It was in the time of great heat that the most beautiful and wonderful things in the world were wrought. It was fierce heat that made the diamond, the sapphire, and the ruby; it fashioned all of the most beautiful forms of crystals and spars; and it ran the gold and silver of the earth in veins, and tossed up mountains, and made hollows for the seas. It is, in short, the temperature at which worlds were born.

More wonderful, if possible, than the miracles wrought by such heat is the fact that men can now produce it artificially; and not only produce, but confine and direct it, and make it do their daily service. One asks himself, indeed, if this can really be; and it was under the impulse of some such incredulity that I lately made a visit to Niagara Falls, where the hottest furnaces in the world are operated. Here clay is melted in vast quantities to form aluminium, a metal as precious a few years ago as gold. Here lime and carbon, the most infusible

of all the elements, are joined by intense heat in the curious new compound, calcium carbide, a bit of which dropped in water decomposes almost explosively, producing a new illuminating gas, acetylene. Here, also, pure phosphorus and the phosphates are made in large quantities; and here is made carborundum — gem-crystals as hard as the diamond and as beautiful as the ruby.

An extensive plant has also been built to produce the heat necessary to make graphite such as is used in your lead-pencils, and for lubricants, stove-blacking, and so on. Graphite has been mined from the earth for thousands of years; it is pure carbon, first cousin to the diamond. Ten years ago the possibility of its manufacture would have been scouted as ridiculous; and yet in these wonderful furnaces, which repeat so nearly the processes of creation, graphite is as easily made as soap. The marvel-workers at Niagara Falls have not yet been able to make diamonds — in quantities. The distinguished French chemist Moissan has produced them in his laboratory furnaces — small ones, it is true, but diamonds; and one day they may be shipped in peck boxes from the great furnaces at Niagara Falls. This is no mere dream; the commercial manufacture of diamonds has already had the serious consideration of level-headed, far-seeing business men, and it may be accounted a distinct probability. What revolution the achievement of it would work in the diamond trade as now constituted and conducted no one can say.

These marvelous new things in science and invention have been made possible by the chaining of Niagara to the wheels of industry. The power of the falling water is transformed into electricity. Electricity and heat are both vibratory motions of the ether; science has found that the vibrations known as electricity can be changed into the vibrations known as heat. Accordingly, a thousand horse-power from the mighty river is conveyed as electricity over a copper wire, changed into heat and light between the tips of carbon electrodes, and there works its wonders. In principle the electrical furnace is identical with the electric light. It is scarcely twenty years since the first electrical furnaces of real practical utility were constructed; but if the electrical furnaces to-day in operation at Niagara Falls alone were combined into one, they would, as one scientist

speculates, make a glow so bright that it could be seen distinctly from the moon — a hint for the astronomers who are seeking methods for communicating with the inhabitants of Mars. One furnace has been built in which an amount of heat energy equivalent to 700 horse-power is produced in an arc cavity not larger than an ordinary water tumbler.

On reaching Niagara Falls, I called on Mr. E. G. Acheson, whose name stands with that of Moissan as a pioneer in the investigation of high temperatures. Mr. Acheson is still a young man — not more than forty-five at most — and clean-cut, clear-eyed, and genial, with something of the studious air of a college professor. He is pre-eminently a self-made man. At twenty-four he found a place in Edison's laboratory — "Edison's college of inventions," he calls it — and, at twenty-five, he was one of the seven pioneers in electricity who (in 1881-82) introduced the incandescent lamp in Europe. He installed the first electric-light plants in the cities of Milan, Genoa, Venice, and Amsterdam, and during this time was one of Edison's representatives in Paris.

"I think the possibility of manufacturing genuine diamonds," he said to me, "has dazzled more than one young experimenter. My first efforts in this direction were made in 1880. It was before we had command of the tremendous electric energy now furnished by the modern dynamo, and when the highest heat attainable for practical purposes was obtained by the oxy-hydrogen flame. Even this was at the service of only a few experimenters, and certainly not at mine. My first experiments were made in what I might term the 'wet way'; that is, by the process of chemical decomposition by means of an electric current. Very interesting results were obtained, which even now give promise of value; but the diamond did not materialize.

"I did not take up the subject again until the dynamo had attained high perfection and I was able to procure currents of great power. Calling in the aid of the 6,500° Fahrenheit or more of temperature produced by these electric currents, I once more set myself to the solution of the problem. I now had, however, two distinct objects in view: first, the making of a diamond; and, second, the production of a hard substance for abrasive purposes. My experiments in 1880 had resulted in producing

a substance of extreme hardness, hard enough, indeed, to scratch the sapphire — the next hardest thing to the diamond — and I saw that such a material, cheaply made, would have great value.

"My first experiment in this new series was of a kind that would have been denounced as absurd by any of the old-school book-chemists, and had I had a similar training, the probability is that I should not have made such an investigation. But 'fools rush in where angels fear to tread,' and the experiment was made."

This experiment by Mr. Acheson, extremely simple in execution, was the first act in rolling the stone from the entrance to a veritable Aladdin's cave, into which a multitude of experimenters have passed in their search for nature's secrets; for, while the use of the electrical furnace in the reduction of metals — in the breaking down of nature's compounds — was not new, its use for synthetic chemistry — for the putting together, the building up, the formation of compounds — was entirely new. It has enabled the chemist not only to reproduce the compounds of nature, but to go further and produce valuable compounds that are wholly new and were heretofore unknown to man. Mr. Acheson conjectured that carbon, if made to combine with clay, would produce an extremely hard substance; and that, having been combined with the clay, if it should in the cooling separate again from the clay, it would issue out of the operation as diamond. He therefore mixed a little clay and coke dust together, placed them in a crucible, inserted the ends of two electric-light carbons into the mixture, and connected the carbons with a dynamo. The fierce heat generated at the points of the carbons fused the clay, and caused portions of the carbon to dissolve. After cooling, a careful examination was made of the mass, and a few small purple crystals were found. They sparkled with something of the brightness of diamonds, and were so hard that they scratched glass. Mr. Acheson decided at once that they could not be diamonds; but he thought they might be rubies or sapphires. A little later, though, when he had made similar crystals of a larger size, he found that they were harder than rubies, even scratching the diamond itself. He showed them to a number of expert jewelers, chemists, and geologists. They had so much the appearance of natural gems that many ex-

perts to whom they were submitted without explanation decided that they must certainly be of natural production. Even so eminent an authority as Geikie, the Scotch geologist, on being told, after he had examined them, that the crystals were manufactured in America, responded testily: "These Americans! What won't they claim next? Why, man, those crystals have been in the earth a million years."

Mr. Acheson decided at first that his crystals were a combination of carbon and aluminium, and gave them the name carborundum. He at once set to work to manufacture them in large quantities for use in making abrasive wheels, whetstones, and sandpaper, and for other purposes for which emery and corundum were formerly used. He soon found by chemical analysis, however, that carborundum was not composed of carbon and aluminium, but of carbon and silica, or sand, and that he had, in fact, created a new substance; so far as human knowledge now extends, no such combination occurs anywhere in nature. And it was made possible only by the electrical furnace, with its power of producing heat of untold intensity.

In order to get a clear understanding of the actual workings of the electrical furnace, I visited the plant where Mr. Acheson makes carborundum. The furnace-room is a great, dingy brick building, open at the sides like a shed. It is located only a few hundred yards from the banks of the Niagara River and well within the sound of the great falls. Just below it, and nearer the city, stands the handsome building of the Power Company, in which the mightiest dynamos in the world whir ceaselessly, day and night, while the waters of Niagara churn in the water-wheel pits below. Heavy copper wires carrying a current of 2,200 volts lead from the power-house to Mr. Acheson's furnaces, where the electrical energy is transformed into heat.

There are ten furnaces in all, built loosely of fire-brick, and fitted at each end with electrical connections. And strange they look to one who is familiar with the ordinary fuel furnace, for they have no chimneys, no doors, no drafts, no ash-pits, no blinding glow of heat and light. The room in which they stand is comfortably cool. Each time a furnace is charged it is built up anew; for the heat produced is so fierce that it frequently melts the bricks together, and new ones must be

supplied. There were furnaces in many stages of development. One had been in full blast for nearly thirty hours, and a weird sight it was. The top gave one the instant impression of the seamy side of a volcano. The heaped coke was cracked in every direction, and from out of the crevices and depressions and from between the joints of the loosely built brick walls gushed flames of pale green and blue, rising upward, and burning now high, now low, but without noise beyond a certain low humming. Within the furnace — which was oblong in shape, about the height of a man, and sixteen feet long by six wide — there was a channel, or core, of white-hot carbon in a nearly vaporized state. It represented graphically in its seething activity what the burning surface of the sun might be — and it was almost as hot. Yet the heat was scarcely manifest a dozen feet from the furnace, and but for the blue flames rising from the cracks in the envelope, or wall, one might have laid his hand almost anywhere on the bricks without danger of burning it.

In the best modern blast-furnaces, in which the coal is supplied with special artificial draft to make it burn the more fiercely, the heat may reach 3,000 degrees Fahrenheit. This is less than half of that produced in the electrical furnace. In porcelain kilns, the potters, after hours of firing, have been able to produce a cumulative temperature of as much as 3,300 degrees Fahrenheit; and this, with the oxyhydrogen flame (in which hydrogen gas is spurred to greater heat by an excess of oxygen), is the very extreme of heat obtainable by any artificial means except by the electrical furnace. Thus the electrical furnace has fully doubled the practical possibilities in the artificial production of heat.

Mr. Fitzgerald, the chemist of the Acheson Company, pointed out to me a curious glassy cavity in one of the half-dismantled furnaces. "Here the heat was only a fraction of that in the core," he said. But still the fire-brick — and they were the most refractory produced in this country — had been melted down like butter. The floors under the furnace were all made of fire-brick, and yet the brick had run together until they were one solid mass of glassy stone. "We once tried putting a fire-brick in the center of the core," said Mr. Fitzgerald, "just to test the heat. Later, when we came to open the fur-

BLOWING OFF.

"Not infrequently gas collects, forming a miniature mountain, with a crater at its summit, and blowing a magnificent fountain of flame, lava, and dense, white vapor high into the air, and roaring all the while in a most terrifying manner."

nace, we couldn't find a vestige of it. The fire had totally consumed it, actually driving it all off in vapor."

Indeed, so hot is the core that there is really no accurate means of measuring its temperature, although science has been enabled by various curious devices to form a fairly correct estimate. The furnace has a provoking way of burning up all of the thermometers and heat-measuring devices which are applied to it. A number of years ago a clever German, named Segar, invented a series of little cones composed of various infusible earths like clay and feldspar. He so fashioned them that one in the series would melt at 1,620 degrees Fahrenheit, another at 1,800 degrees, and so on up. If the cones are placed in a pottery kiln, the potter can tell just what degree of temperature he has reached by the melting of the cones one after another. But in Mr. Acheson's electrical furnaces all the cones would burn up and disappear in two minutes. The method employed for coming at the heat of the electrical furnace, in some measure, is this: a thin filament of platinum is heated red hot — 1,800 degrees Fahrenheit — by a certain current of electricity. A delicate thermometer is set three feet away, and the reading is taken. Then, by a stronger current, the filament is made white hot — 3,400 degrees Fahrenheit — and the thermometer moved away until it reads the same as it read before. Two points in a distance-scale are thus obtained as a basis of calculation. The thermometer is then tried by an electrical furnace. To be kept at the same marking it must be placed much farther away than in either of the other instances. A simple computation of the comparative distances with relation to the two well-ascertained temperatures gives approximately, at least, the temperature of the electrical furnace. Some other methods are also employed. None is regarded as perfectly exact; but they are near enough to have yielded some very interesting and valuable statistics regarding the power of various temperatures. For instance, it has been found that aluminium becomes a limpid liquid at from 4,050 to 4,320 degrees Fahrenheit, and that lime melts at from 4,940 to 5,400 degrees, and magnesia at 4,680 degrees.

There are two kinds of electrical furnaces, as there are two kinds of electric lights — arc and incandescent. Moissan has used the arc furnace in all of his experiments, but Mr. Acheson's

furnaces follow rather the principle of the incandescent lamp. "The incandescent light," said Mr. Fitzgerald, "is produced by the resistance of a platinum wire or a carbon filament to the passage of a current of electricity. Both light and heat are given off. In our furnace, the heat is produced by the resistance of a solid cylinder or core of pulverized coke to the passage of a strong current of electricity. When the core becomes white hot it causes the materials surrounding it to unite chemically, producing the carborundum crystals."

The materials used are of the commonest — pure white sand, coke, sawdust, and salt. The sand and coke are mixed in the proportions of sixty to forty, the sawdust is added to keep the mixture loose and open, and the salt to assist the chemical combination of the ingredients. The furnace is half filled with this mixture, and then the core of coke, twenty-one inches in diameter, is carefully molded in place. This core is sixteen feet long, reaching the length of the furnace, and connecting at each end with an immense carbon terminal, consisting of no fewer than twenty-five rods of carbon, each four inches square and nearly three feet long. These terminals carry the current into the core from huge insulated copper bars connected from above. When the core is complete, more of the carborundum mixture is shoveled in and tamped down until the furnace is heaping full.

Everything is now ready for the electric current. The wires from the Niagara Falls power-plant come through an adjoining building, where one is confronted, upon entering, with this suggestive sign:

DANGER
2,200 Volts.

Tesla produces immensely higher voltages than this for laboratory experiments, but there are few more powerful currents in use in this country for practical purposes. Only about 2,000 volts are required for executing criminals under the electric method employed in New York; 400 volts will run a trolley-car. It is hardly comfortable to know that a single touch of one of the wires or switches in this room means almost certain death. Mr. Fitzgerald gave me a vivid demonstration of the

terrific destructive force of the Niagara Falls current. He showed me how the circuit was broken. For ordinary currents, the breaking of a circuit simply means a twist of the wrist and the opening of a brass switch. Here, however, the current is carried into a huge iron tank full of salt water. The attendant, pulling on a rope, lifts an iron plate from the tank. The moment it leaves the water, there follow a rumbling crash like a thunder-clap, a blinding burst of flame, and thick clouds of steam and spray. The sight and sound of it make you feel delicate about interfering with a 2,200-volt current.

This current is, indeed, too strong in voltage for the furnaces, and it is cut down, by means of what were until recently the largest transformers in the world, to about 100 volts, or one-fourth the pressure used on the average trolley line. It is now, however, a current of great intensity — 7,500 amperes, as compared with the one-half ampere used in an incandescent lamp; and it requires eight square inches of copper and 400 square inches of carbon to carry it.

Within the furnace, when the current is turned on, a thousand horse-power of energy is continuously transformed into heat. Think of it! Is it any wonder that the temperature goes up? And this is continued for thirty-six hours steadily, until 36,000 "horse-power hours" are used up and 7,000 pounds of the crystals have been formed. Remembering that 36,000 horse-power hours, when converted into heat, will raise 72,000 gallons of water to the boiling point, or will bring 350 tons of iron up to a red heat, one can at least have a sort of idea of the heat evolved in a carborundum furnace.

When the coke core glows white, chemical action begins in the mixture around it. The top of the furnace now slowly settles, and cracks in long, irregular fissures, sending out a pungent gas which, when lighted, burns lambent blue. This gas is carbon monoxide, and during the process nearly six tons of it are thrown off and wasted. It seems, indeed, a somewhat extravagant process, for fifty-six pounds of gas are produced for every forty of carborundum.

"It is very distinctly a geological condition," said Mr. Fitzgerald; "crystals are not only formed exactly as they are in the earth, but we have our own little earthquakes and volcanoes." Not infrequently gas collects, forming a miniature

mountain, with a crater at its summit, and blowing a magnificent fountain of flame, lava, and dense white vapor high into the air, and roaring all the while in a most terrifying manner. The workmen call it "blowing off."

At the end of thirty-six hours the current is cut off, and the furnace is allowed to cool, the workmen pulling down the brick as rapidly as they dare. At the center of the furnace, surrounding the core, there remains a solid mass of carborundum as large in diameter as a hogshead. Portions of this mass are sometimes found to be composed of pure, beautifully crystalline graphite. This in itself is a surprising and significant product, and it has opened the way directly to graphite-making on a large scale. An important and interesting feature of the new graphite industry is the utilization it has effected of a product from the coke regions of Pennsylvania which was formerly absolute waste.

To return to carborundum: when the furnace has been cooled and the walls torn away, the core of carborundum is broken open, and the beautiful purple and blue crystals are laid bare, still hot. The sand and the coke have united in a compound nearly as hard as the diamond and even more indestructible, being less inflammable and wholly indissoluble in even the strongest acids. After being taken out, the crystals are crushed to powder and combined in various forms convenient for the various uses for which it is designed.

I asked Mr. Acheson if he could make diamonds in his furnaces. "Possibly," he answered, "with certain modifications." Diamonds, as he explained, are formed by great heat and great pressure. The great heat is now easily obtained, but science has not yet learned nature's secret of great pressure. Moissan's method of making diamonds is to dissolve coke dust in molten iron, using a carbon crucible into which the electrodes are inserted. When the whole mass is fluid, the crucible and its contents are suddenly dashed into cold water or melted lead. This instantaneous cooling of the iron produces enormous pressure, so that the carbon is crystallized in the form of diamond.

But whatever it may or may not yet be able to do in the matter of diamond-making, there can be no doubt that the possibilities of the electrical furnace are beyond all present conjecture. With American inventors busy in its further devel-

opment, and with electricity as cheap as the mighty power of Niagara can make it, there is no telling what new and wonderful products, now perhaps wholly unthought-of by the human race, it may become possible to manufacture, and manufacture cheaply.

UNSOLVED PROBLEMS OF CHEMISTRY.

By IRA REMSEN, LL.D.

THE first duty of the chemist is to examine every kind of matter accessible to him and to determine whether it is an element or not. If it is not, and this is usually the case as regards the things found in nature, his next duty is to attack the compound in every way that is likely to lead to its decomposition, and when he reaches a substance from which he cannot get simpler ones, he calls this an element. Thus iron, copper, gold, silver, tin, hydrogen, and oxygen are elements. None of these can be decomposed by the means at present at the command of the chemist. They are like the letters of a language in some respect. Words can be decomposed or resolved into letters, but letters are the elements of language. What elements are in the earth, in the air, in water? An immense amount of work has been done that has had for its object the answering of this question. The earth has been ransacked almost from pole to pole. The air from all sorts of localities has been examined. The waters, from ocean, rivers, and springs, have been made to stand and answer the searching questions of the chemist; and animals and plants have been compelled to give up their secrets — or some of them.

What is the result? In brief, it is this: Although we find an infinite number of kinds of matter, all of these can be resolved into a comparatively small number of elements. Indeed, not more than a dozen of these elements enter into the composition of the things that are at all common. But by going into out-of-the-way corners rare things have been found, and from these, in turn, rare elements have been obtained. Altogether, between seventy and eighty elements have been found. Additions are made to the list from time to time; and, occasionally, one of the substances supposed to be an element is

found to be capable of decomposition, and it therefore becomes necessary to strike it from the list of elements.

Out of these simplest forms of matter everything that we see or feel, or are in any way cognizant of, is made up. But now arises the deep question: *What is an element?* To this question chemists are not able to give an answer. The relations of the elements to one another form one of the unsolved problems of chemistry. It may be that they are not related at all, but that each one is an independent form of matter. There are, however, indications of family relationships between them that have long been the subject of investigation. The elements fall into groups, the members of which resemble one another very closely in some respects. Thus, for example, phosphorus and arsenic conduct themselves, in general, alike toward other elements. They combine with them to form compounds that are very much alike — so much so that in some cases it is difficult to tell them apart. These elements are said to belong to the same family. The family traits are easily recognized in them. Similar relationships are met with throughout the entire list of elements. This subject has been beautifully worked out by the Russian chemist Mendeléef and the German, Lothar Meyer. The former, indeed, pointed out, thirty years ago, that some of the families are not complete. There were a number of vacant chairs. He was able to predict the discovery of some of these missing members and to describe them in detail. Three of these have since been discovered, and they have been found to answer the description given by Mendeléef before their discovery. Now that the way has been pointed out, it is a comparatively simple thing to predict the discovery of other elements. The vacant chairs are there, but though the elements that are eventually to occupy them are probably hidden away somewhere in the earth, they have thus far eluded the chemist.

As regards the character of the relationships that exist between the elements, it is difficult, or, rather, quite impossible, to speak with confidence. Apparently, the elements are brothers and sisters. We want to find the fathers and mothers. But it appears that they are no longer living. The plain question that we cannot help asking is: Have the elements existed from the beginning of time, or have they been formed from a smaller number of simpler forms of matter? Of course, one can specu-

late on such a subject, but can one speculate profitably? It may as well be acknowledged at once that we know practically nothing in regard to the origin of the elements, or of the cause of the relationships that are so easily recognized.

It has been suggested that the elements are the products of an evolutionary process that has been in progress from the beginning, and that they all owe their existence to a primordial form of matter, simpler than any one of the so-called elements. Some evidence in favor of this view seems to be furnished by the spectroscopic examination of celestial bodies. The nebulæ have been shown to contain the smallest number of our chemical elements; the hotter stars are somewhat more complex; in the colored stars and the sun a large number of elements appear; while the planets are the most complex. The complexity seems to depend upon the temperature. The higher the temperature, the smaller the number of kinds of matter present. Now, may it not be that the elements known to us are derived from simpler forms, or from one single simplest form? We can only answer — it may. If this is the true conception of the relations between the elements, then "in the beginning" space must have been filled with an incandescent vapor made up of the simplest form of matter. As this has cooled, it has taken other forms, and some of these are the things we now call elements. But this shows how easy it is to relapse into the ways of our forefathers and let our imaginations run wild.

Another unsolved problem of chemistry is that presented by the fundamental constituents of plants and animals. No one knows better than the chemist that all living things are "fearfully and wonderfully made." Plants take materials of various kinds from the air and from the earth, and work them up in proper shape for their growth. In turn, animals take parts of some plants or parts of some animals, and work them up so that they become part and parcel of the animal bodies. Life and growth of plant and animal depend upon this power to convert food into other things that can take their proper places in the body. Chemical change is the beginning of life. But what are these things that are formed within the plant and animal? That is a hard question to answer; and, indeed, the answer would be confusing. All that need be said is that among these things are the fats, sugar, starch, cellulose, and a group

of important compounds called proteids. Besides these, there are innumerable substances found both in plants and animals. Naturally, chemists are interested in these things, and they have given, and are giving, much time to their investigation. It is only through such study that we can hope ever to gain any conception of the changes that are taking place in living things, or of the nature of life in its various forms.

Of the substances mentioned, the fats are relatively the simplest, and they are, accordingly, pretty well understood. It is interesting to note in passing that the first and the most important chemical investigation in fats was carried out at the beginning of this century by the French chemist Chevreul, who died only a few years ago at the age of 103, having kept in harness to the last. Regarding our knowledge of fats, it is safe to say that we know enough about them to be able to see how one could, starting with carbon, hydrogen, and oxygen, which are the only elementary substances found in the fats — how one could make in the laboratory the same fats that occur in living things. No one has ever done this, but it appears highly probable that, with unlimited time at one's disposal, it could be done by making use of methods that are made use of every day in the laboratory. Not many years ago that statement would have been challenged. The constituents of plants and animals were supposed to be entirely different from the constituents of the manimate inorganic parts of the earth, and it was further supposed that those substances which are elaborated under the influence of the life-process cannot be formed without this influence. This may be true of the most complex constituents of plants and animals, but it is certainly not true of some of the simpler of these constituents. For example, urea, one of the most characteristic substances formed in the animal body, was made in the laboratory in 1828, by a method which was entirely independent of the life-process; and since that time innumerable other substances which are characteristic products of the life-process have been made artificially. So that, as we know very well what fats are, and can make substances of the same kind in the laboratory, there is nothing out of the way in saying that the fats could probably be made artificially. Let us assume that they can be. What then?

Next in order of complexity come the so-called carbohydrates,

which include the sugars, starch, and cellulose. Is it "highly probable" that the chemist can build these up out of the elements in the laboratory? Thanks to Emil Fischer, of Berlin, we can now almost say that sugar is not an unsolved problem. Within the last few years more has been done to clear up the problem of the sugars than in all preceding time put together. One of the simplest sugars has been prepared artificially in the laboratory, and the relations between the others have been, to a large extent, revealed.

But the sugars are simple things compared with starch. Starch *is* an unsolved problem. It is of the highest importance in Nature. Its wide distribution among plants and the part that it plays as a constituent of foods show this. What is it? Of course, if we say it is a carbohydrate, we have made the whole subject clear! The truth is we know very little about it, in spite of the large amount of work that has been done on it. In what has been done there is little promise of success, though the chemical optimist hopes, even in the face of starch. I confess to being a moderate optimist. If asked why I hope in this case, I could only answer, "I hope — that is all."

Let us take the next step. This brings us to cellulose, a substance of very great importance for all plants. It forms, as it were, their skeletons. Just as animals are built upon a basis of bone, so plants are built upon a basis of cellulose. It is that constituent of plants that gives them form and that enables them to resist the disintegrating influences to which they are subject in Nature. When a piece of wood is treated with certain active substances, "chemicals" as they are called by the outside world, many of the constituents are destroyed and removed, and, finally, what is known as wood-pulp remains. This is mainly cellulose. As is well known, large quantities of paper are made from this pulp. Paper is, in fact, more or less pure cellulose. Every plant contains cellulose, and without it the plants could not exist. It seems as though a chemist ought to feel humiliated to have to confess that even less is known about cellulose than about starch. There appears to be some reason for believing that it is distantly related to starch, but that is about all we can say. It is probably enormously complicated. To be sure, it contains only the three elements, carbon, hydrogen, and oxygen, but these three elements can combine with

one another in thousands of different ways, forming, on the one hand, relatively simple products, and, on the other, products of such complexity that before them the chemist can only stand and wonder. Cellulose belongs to the latter class.

Finally, let us remove our hats and shoes, and, bowing low, ask with bated breath: — What about the proteids? What about them, indeed? Let us, rather, go back to cellulose and starch and recover our courage and our heads. This atmosphere is stifling. I always feel like running away when any one begins to talk about proteids in my presence, and here I am, trying to write something about them. I ought to be ashamed of myself. Quoting from a text-book of physiology: "These (proteids) form the principal solids of the muscular, nervous, and glandular tissues, of the serum of blood, of serous fluids, and of lymph." That tells the story. What could we do without them? It is not for me to say what we know about proteids. In my youth I had a desire to attack these dragons, but now I am afraid of them. Fortunately, there is no occasion here for enlarging upon them. I only want to make clear the fact that they are unsolved problems of chemistry; and, let me add, they are likely to remain such for generations to come. Yet every one who knows anything about chemistry and physiology knows that these proteids must be understood, before we can hope to have a clear conception of the chemical processes of the human body. Fortunately for us, there are always some chemists who delight in working upon the most difficult problems and are not willing to take "No" for an answer. So that there is always some one working on the proteids, and something is coming of it.

In the field of synthetic chemistry perhaps the most important problem among those that are unsolved is that presented by *protoplasm*. I have recently heard of a school, and a primary school at that, where the small children are introduced to the mysteries of life by being told "all about" protoplasm. If I were a pupil in that school, I might be able to tell my readers what protoplasm is, but, as I have not that privilege, I shall have to acknowledge that I know very little about it. In fact, it is a substance, or a mixture of substances, with which the chemist can do very little. Great interest has been taken in all that pertains to protoplasm, because it is so directly connected with life. The simplest organisms are the *amœbæ*. These may

be regarded as representing life reduced to its lowest form. Now an *amœba* "is wholly, or almost wholly protoplasm." "It lives, moves, eats, grows, and, after a time, dies, having been, during its whole life, hardly anything more than a minute lump of protoplasm"—(Foster). Regarded as a chemical substance, it contains the elements oxygen, hydrogen, nitrogen, carbon, and sulphur in fairly constant proportions. It would be a great day for chemistry if a chemist should succeed in putting together, and causing to unite, the above-named elements in the proportions in which they are present in protoplasm, and he should find that he had made protoplasm artificially. If this artificial protoplasm should move and eat and grow, he would deserve to be ranked with Pygmalion of old. What are the prospects?

In the first place, protoplasm does not appear to be a single substance, but a mixture of substances. It contains something that is derived from a proteid, something else derived from a fat, and still a third something derived from a carbohydrate. Perhaps these three things are chemically united with one another, and not simply mixed. The problem presented to the chemist is one of the greatest difficulty. It would be necessary for him to determine exactly what proteid, what fat, and what carbohydrate are essential to the existence of protoplasm; then to bring these together, and show that the substance thus obtained is identical with protoplasm. This might be accomplished, and yet the protoplasm obtained not be a living thing; for there is dead, as well as living, protoplasm. There is no evidence that any chemist is engaged in attempts to make protoplasm in the laboratory. Possibly some are dreaming of this problem, but dreams are generally harmless, and sometimes they are pleasant, and, indeed, useful. Before we can understand, if we ever are to understand, the difference between a living and a dead tissue, we must understand what protoplasm is, and our chances of solving the problem presented by this important basis of life are extremely poor. Still, we may hope to get nearer its solution by continued investigation, and we shall have to be satisfied with small returns for our labor.

Chemistry has to deal with the composition of things, and the changes in the composition of things, and all that pertains to these subjects. Changes in composition are often brought

about by raising the temperature. To take a comparatively simple, though not a familiar, example, water is a compound of the elements of hydrogen and oxygen. When this is heated, it is converted into water-vapor. When this vapor is heated to 4,500 degrees Fahrenheit, it is resolved into hydrogen and oxygen. At this temperature the compound, water, cannot exist. On the other hand, when hydrogen and oxygen are brought together at ordinary temperatures, they do not combine to form water, unless a spark or a flame is brought in contact with the mixture, when a violent explosion occurs, and this is the signal of the chemical union of the two elements to form water. Again, when wood is heated, it gives off gases and liquids, and at last there is nothing left but charcoal, which is one form of the element carbon. It is plain that some substances, that can exist at ordinary temperature, are decomposed — that is to say, they cannot exist — at high temperatures. This is, in fact, true of many of the substances familiar to us. But heat not only decomposes compounds; it also, if not too intense, causes elements to combine to form compounds. In the laboratory and in the factory heat is constantly being employed for the purpose of bringing about, or aiding, chemical action. The blast-furnace, from which comes all our iron, is a good example. The object in view is the separation of the metal, iron, from its ores. The ores consist of iron in combination with oxygen and, sometimes, other things; but it is the oxygen that gives the principal difficulty. When the compound of iron and oxygen is heated with something that, under the circumstances, has the power to combine with the oxygen and escape with it in the form of a gas, the iron is left behind. Charcoal or coke is used for this purpose. At high temperatures, these substances, which are different forms of the element carbon, take the oxygen from the iron, and the metal liberated sinks to the bottom of the furnace in the molten state, while the gaseous compound of carbon and oxygen passes out of the top of the furnace. The oxygen changes partners. It is to be observed that the iron ore might be mixed with the charcoal, and the mixture allowed to stand at ordinary temperatures for any length of time, without separation of iron. Heat is necessary, and a good deal of it, to cause the charcoal to unite with the oxygen and carry it off into space.

Heat being an important factor in chemical acts, the question suggests itself: What will be the effect upon chemical processes if the temperature is raised much above the range within which we ordinarily work? And at the same time the complementary question will suggest itself: What will be the effect of lowering the temperature much below that at which we ordinarily work?

Until within the last few years the highest temperatures attainable were reached by the aid of the so-called compound blowpipe, which is an instrument for burning hydrogen, or some other combustible gas, in oxygen under pressure. By the aid of this instrument platinum was melted and, in one case, silver was boiled. But now the introduction of powerful electric currents has made the production of much higher temperatures possible, and marvelous results have been reached. M. Moissan, of Paris, has for some time been engaged in studying the chemical effects of high temperatures, and to him we owe almost all we know of chemistry at these temperatures. He has made use of a simple contrivance, which he calls an electric furnace. In this he has subjected many things to temperatures as high as from 6,000 to 7,000 degrees Fahrenheit. It is a pity that Dante could not have taken a course in chemistry under M. Moissan. These temperatures, notwithstanding their great height, are suggestive of the lower regions. This work has opened up a new world to chemists, and has shown them that there are many unsolved problems to be found here. Things that unite readily at ordinary high temperatures do not act at all at these higher temperatures; and things that do not act at all at the former act vigorously at the latter. There is no end of what may be learned in this new field.

Just as it is desirable to know how things act upon one another at high temperatures, so it is equally desirable to know how they act at low temperatures. Curiously enough, work in this direction has kept pace with that in the opposite direction, referred to in the last paragraph. Within the last year or two, the attention of everybody has been directed to low temperatures by the interesting work that has been done on liquid air. It is well known that air can now be liquefied on the large scale, and that liquid air is an article of commerce. This brings low temperatures to our door, for it is only necessary to expose the liquid in an open vessel to produce a temperature of about 300

degrees below zero, Fahrenheit! Then, further, Dewar has recently succeeded in liquefying and, indeed, solidifying hydrogen — a much more difficult feat than liquefying air — and with the solid thus produced he has reached the temperature 432 degrees below zero, Fahrenheit! There is no serious difficulty then, at present, in studying chemical action at temperatures in the neighborhood of 300 degrees below zero. The first results are not reassuring. Things are not very lively down there, to say the least. It may be that all chemical action ceases below a certain temperature, but we do not, as yet, know enough about this subject to justify us in speaking with confidence about it. Countless experiments yet unborn will have to be tried. In thinking of the possibilities, we are confronted with what appears to be a paradox. It has been pointed out that high temperature, in many cases, has the effect of decomposing substances. This shows that these substances are more stable at low temperatures than at the ordinary temperatures. In other words, if heat causes the constituents to separate, cold might apparently cause them to unite more firmly. But, if this is so, why do not substances act upon each other readily at low temperatures? It may be that the constituents are so firmly held together that they cannot move about among one another, as they must in order to combine. The water that is frozen in a glacier does not act like water at ordinary temperatures. It is, as it were, chained up and prevented from obeying the laws of water.

In what I have thus far had to say, I have kept in view certain problems which do not necessarily call for much speculation. It would, however, hardly be fair to leave the speculative side of chemistry entirely out of consideration. Sometimes young pupils are introduced to chemistry through the atom. Only very young, or very ignorant, persons can talk with confidence about atoms. The further one goes into the mysteries of chemistry, the more mysterious appears the atom. In fact, the atom is the great unsolved problem of chemistry. But this is subtle. What is an atom? Ah! that is the question. It has been a favorite subject of thought from the earliest days. Up to the beginning of this century, however, it was nothing but a metaphysical plaything. The wits of generations of philosophers have been sharpened by efforts to decide whether matter is infinitely divisible or not. Take a piece of, say, iron. No

matter what its size may be, it can be broken up into smaller pieces; and each of the pieces thus obtained can be still further subdivided. Now, how far can this process of subdivision be carried? Is there any limit? The atomists held that, after a time, particles would be reached so small that they could not be made smaller. But their opponents said, "No! this is inconceivable. Matter must be infinitely divisible." As neither side could prove the other wrong, the question under discussion was well adapted to the purposes of controversy.

The atom of to-day is a scientific abstraction. Many facts have been brought to light that make it appear certain that matter is not continuous — is not capable of infinite subdivision. Dalton, the Quaker schoolmaster of Manchester, was the first one to bring the atom down to the earth and make it a useful idea. How he did this cannot be shown here. Suffice it to say, the *atomic theory* proposed by Dalton in the early years of this century lives to-day, and is stronger than it has ever been, notwithstanding the efforts that have been made to show that it is built upon sand. It has been, and is to-day, an extremely useful theory. Whether it will always continue to be so is another question, and one that need not bother us. It is believed that each elementary substance — that is to say, each chemical element — consists of minute particles that are not broken up in the course of chemical changes. These particles that remain intact are the atoms of chemistry. Some such theory is absolutely necessary to account for the fundamental laws of chemistry.

Into what thin air we enter, when we begin to speak of the properties of the individual atom, will appear when it is stated that, according to the calculations of Lord Kelvin, the molecule of hydrogen, which is at least twice as large as its atom, is of such size that it would take 50,000,000 of them placed in a row to occupy an inch! To be sure, most atoms are larger than those of hydrogen, but there are few so large that it would not be necessary to have about a million of them to occupy an inch. What sense is there in talking about such things? We shall never be able to see them, or to prove that they exist. True, but the conception of the atom has been of great help to chemists, and, as long as it continues to be helpful, it will be clung to.

If the views held by the majority of chemists are true, the science of chemistry is the science of atoms. The astronomer has to deal with infinite distances and the largest masses in the universe. The chemist, on the other hand, has to deal with the shortest distances and the minutest particles of matter. The astronomer uses the telescope, but there is no microscope that can carry us to the atom. The astronomer observes points of light, follows their motions, and works out the laws that govern them. The chemist has troubles of another kind. He cannot deal directly with single atoms. No matter how small a quantity of an element he may use in his experiment, he has to deal with a large number of atoms. Every time he performs an experiment millions of atoms come into play. He studies his substances before action and after action. New substances are formed, and he concludes the atoms have arranged themselves in different ways. What he *knows* is that new substances with new properties are formed. He knows this whether atoms are realities or not, but the atom helps him to form a picture of what probably takes place throughout the masses with which he is dealing. The atoms are as far removed from the intellectual gaze of the chemist as the most remote stars from the eye of the astronomer.

Yet the chemist talks about the way in which atoms are combined with one another; and he draws figures, and constructs models to show it all. And he doesn't do this for his amusement, but because he is helped by it. He talks in the language of chemistry, as the mathematician talks in the language of mathematics. Some day he will, no doubt, understand the language better. Probably the language itself will be changed, and that which he now uses will seem like the prattle of an infant.

One other side of chemistry must be turned into view before I can close. I am not sure that I can make myself intelligible in what I still have to say, but I shall try. Thus far, in what has been said about chemical acts, the material side has been kept in view. The relations between the elements; the artificial preparation of the substances that enter into the composition of living things; the changes in the composition of matter at high and at low temperatures; and, finally, the atom — these are the subjects dealt with. But, whenever a chemical act takes place, there are changes in the temperature and in the electrical

condition of the substances involves, in addition to the changes in composition. It is while in action that chemical substances are most interesting. Generally we have to content ourselves with observations before and after an act, but we should learn a great deal more about the nature of the act, if we could make observations while it is in progress. We should find it very difficult, if not impossible, to learn the law of falling bodies, if we could only observe bodies before and after they have fallen; but by observing them in the act of falling we can, without difficulty, deduce the law.

Generally speaking, chemical acts are so rapid that it is impossible to make observations during their course. Much progress has been made in this field during the past fifteen or twenty years, and some of the great laws of chemical action have been discovered. What has been learned is, however, only enough to whet the appetite of chemists. To illustrate in another way what is meant by making observations during a chemical act, let us take the case of gunpowder. This usually consists of charcoal, sulphur, and saltpeter. A spark is sufficient to cause the chemical act that is accompanied by the explosion. We can collect everything that is formed, and show what changes in composition have taken place. But we should like to know something about the act itself, and yet, plainly, observations during the act cannot be numerous, or especially instructive. And so it is with most common chemical changes that are studied in the laboratory. We get only snap-shots at them. If we could only get a series of pictures at short intervals, we might, by combining these afterward, get some idea of what is taking place during the act. Fortunately, there are ways of controlling certain classes of chemical acts and reducing their speed, so that observations can be made during their progress; and much has been learned in this way. Here is a great field for further study, and it presents many unsolved problems.

Finally, a few words about water. It is said that a well-known chemist some years ago made a bet that a certain company of chemists could not name a chemical subject that would not, in turn, suggest to him a profitable chemical investigation. Thereupon, after much deliberation, the challenged company suggested "water," on the assumption that this has been thoroughly worked over, and does not present unsolved problems. The result was a

beautiful investigation of some of the properties of water. Every one knows that water is the most abundant substance on the earth. It also plays a more important part in the changes that are taking place on the earth than any other substance. We are only beginning to learn how it acts. That it dissolves many things is well known, but let us not be misled because this phenomenon is so common and so familiar. Put a little salt in water. What becomes of it? It disappears. There is no solid substance in the vessel. We may bandy phrases as we please, but we cannot tell what has become of the salt. We can get the salt out of the water by boiling the solution and letting the water pass off as steam, when the salt will be left behind. As we put the salt in and take it out, we have been accustomed until recently to think of the salt as being present in the solution as such. One of the most important advances in chemistry made of late years is that which leads to the conception that, in dilute solutions at least, there is little, if any, salt present; that, in some way, the water decomposes it into particles highly charged with electricity. These particles are called ions. This idea has thrown a great deal of light upon important problems of chemistry, but it has suggested many new ones. Some substances — for example, sugar — do not act like salt when dissolved in water. Why this difference? Then, too, some liquids which are good solvents do not act at all like water. What is it in water that distinguishes it from most other liquids, such as alcohol and ether, enabling it to tear many substances asunder? These are questions that are now very much to the front. Rapid progress is being made, and we may look for important discoveries in this field in the near future.

THE EXACT MEASUREMENT OF PHENOMENA.

By W. STANLEY JEVONS.

AS physical science advances, it becomes more and more accurately quantitative. Questions of simple logical fact after a time resolve themselves into questions of degree, time, distance or weight. Forces hardly suspected to exist by one generation are clearly recognized by the next, and precisely measured by the third generation. But one condition of this rapid advance is the invention of suitable instruments of measurement. We need what Francis Bacon called *Instantiæ citantes,* or *evocantes,* methods of rendering minute phenomena perceptible to the senses; and we also require *Instantiæ radii* or *curriculi,* that is, measuring instruments. Accordingly, the introduction of a new instrument often forms an epoch in the history of science. As Dady said, "Nothing tends so much to the advancement of knowledge as the application of a new instrument. The native intellectual powers of men in different times are not so much the causes of the different success of their labors as the peculiar nature of the means and artificial resources in their possession."

In the absence indeed of advanced theory and analytical power, a very precise instrument would be useless. Measuring apparatus and mathematical theory should advance *pari passu,* and with just such precision as the theorist can anticipate results, the experimentalist should be able to compare them with experience. The scrupulously accurate observations of Flamsteed were the proper complement to the intense mathematical powers of Newton.

Every branch of knowledge commences with quantitative notions of a very rude character. After we have far progressed, it is often amusing to look back into the infancy of the science and contrast present with past methods. At Greenwich Observa-

tory in the present day the hundredth part of a second is not thought an inconsiderable portion of time. The ancient Chaldæans recorded an eclipse to the nearest hour, and the early Alexandrian astronomers thought it superfluous to distinguish between the edge and the center of the sun. By the introduction of the astrolabe, Ptolemy and the later Alexandrian astronomers could determine the places of the heavenly bodies within about ten minutes of arc. Little progress then ensued for thirteen centuries, until Tycho Brahe made the first great step towards accuracy, not only by employing better instruments, but even more by ceasing to regard an instrument as correct. Tycho, in fact, determined the errors of his instruments, and corrected his observations. He also took notice of the effects of atmospheric refraction, and succeeded in attaining an accuracy often sixty times as great as that of Ptolemy. Yet Tycho and Hevelius often erred several minutes in the determination of a star's place, and it was a great achievement of Rœmer and Flamsteed to reduce this error to seconds. Bradley, the modern Hipparchus, carried on the improvement, his errors in right ascension, according to Bessel, being under one second of time, and those of declination under four seconds of arc. In the present day the average error of a single observation is probably reduced to the half or quarter of what it was in Bradley's time; and further extreme accuracy is attained by the multiplication of observations, and their skilful combination according to the theory of error. Some of the more important constants, for instance, that of nutation, have been determined within the tenth part of a second of space.

It would be a matter of great interest to trace out the dependence of this progress upon the introduction of new instruments. The astrolabe of Ptolemy, the telescope of Galileo, the pendulum of Galileo and Huyghens, the micrometer of Horrocks, and the telescopic sights and micrometer of Gascoygne and Picard, Rœmer's transit instrument, Newton's and Hadley's quadrant, Dollond's achromatic lenses, Harrison's chronometer, and Ramsden's dividing engine — such were some of the principal additions to astronomical apparatus. The result is, that we now take note of quantities 300,000 or 400,000 times as small as in the time of the Chaldæans.

It would be interesting again to compare the scrupulous accuracy of a modern trigonometrical survey with Eratosthenes' rude

but ingenious guess at the difference of latitude between Alexandria and Syene — or with Norwood's measurement of a degree of latitude in 1635. "Sometimes I measured, sometimes I paced," said Norwood; "and I believe I am within a scantling of the truth." Such was the germ of those elaborate geodesical measurements which have made the dimensions of the globe known to us within a few hundred yards.

In other branches of science, the invention of an instrument has usually marked, if it has not made, an epoch. The science of heat might be said to commence with the construction of the thermometer, and it has recently been advanced by the introduction of the thermo-electric pile. Chemistry has been created chiefly by the careful use of the balance, which forms a unique instance of an instrument remaining substantially in the form in which it was first applied to scientific purposes by Archimedes. The balance never has been and probably never can be improved, except in details of construction. The torsion balance, introduced by Coulomb towards the end of last century, has rapidly become essential in many branches of investigation. In the hands of Cavendish and Baily, it gave a determination of the earth's density; applied in the galvanometer, it gave a delicate measure of electrical forces, and is indispensable in the thermo-electric pile. This balance is made by simply suspending any light rod by a thin wire or thread attached to the middle point. And we owe to it almost all the more delicate investigations in the theories of heat, electricity, and magnetism.

Though we can now take note of the millionth of an inch in space, and the millionth of a second in time, we must not overlook the fact that in other operations of science we are yet in the position of the Chaldæans. Not many years have elapsed since the magnitudes of the stars, meaning the amounts of light they send to the observer's eye, were guessed at in the rudest manner, and the astronomer adjudged a star to this or that order of magnitude by a rough comparison with other stars of the same order. To Sir John Herschel we owe an attempt to introduce a uniform method of measurement and expression, bearing some relation to the real photometric magnitudes of the stars. Previous to the researches of Bunsen and Roscoe on the chemical action of light, we were devoid of any mode of measuring the energy of light; even now the methods are tedious, and

it is not clear that they give the energy of light so much as one of its special effects. Many natural phenomena have hardly yet been made the subject of measurement at all, such as the intensity of sound, the phenomena of taste and smell, the magnitude of atoms, the temperature of the electric spark or of the sun's photosphere.

To suppose, then, that quantitative science treats only of exactly measurable quantities, is a gross, if it be a common, mistake. Whenever we are treating of an event which either happens altogether or does not happen at all, we are engaged with a non-quantitative phenomenon, a matter of fact, not of degree; but whenever a thing may be greater or less, or twice or thrice as great as another, whenever, in short, ratio enters even in the rudest manner, there science will have a quantitative character. There can be little doubt, indeed, that every science as it progresses will become gradually more and more quantitative. Numerical precision is the soul of science, as Herschel said, and as all natural objects exist in space, and involve molecular movements, measurable in velocity and extent, there is no apparent limit to the ultimate extension of quantitative science. But the reader must not for a moment suppose that, because we depend more and more upon mathematical methods, we leave logical methods behind us. Number, as I have endeavored to show, is logical in its origin, and quantity is but a development of number, or analogous thereto.

The phenomena of nature are for the most part manifested in quantities which increase or decrease continuously. When we inquire into the precise meaning of continuous quantity, we find that it can only be described as that which is divisible without limit. We can divide a millimetre into ten, or a hundred, or a thousand, or ten thousand parts, and mentally at any rate we can carry on the division *ad infinitum*. Any finite space, then, must be conceived as made up of an infinite number of parts each infinitely small. We cannot entertain the simplest geometrical notions without allowing this. The conception of a square involves the conception of a side and diagonal, which, as Euclid beautifully proves in the 117th proposition of his tenth book, have no common measure, meaning no finite common measure. Incommensurable quantities are, in fact, those which have for their only common measure an infinitely small quantity. It is

somewhat startling to find, too, that in theory incommensurable quantities will be infinitely more frequent than commensurable. Let any two lines be drawn haphazard; it is infinitely unlikely that they will be commensurable, so that the commensurable quantities, which we are supposed to deal with in practice, are but singular cases among an infinitely greater number of incommensurable cases.

Practically, however, we treat all quantities as made up of the least quantities which our senses, assisted by the best measuring instruments, can perceive. So long as microscopes were uninvented, it was sufficient to regard an inch as made up of a thousand thousandths of an inch; now we must treat it as composed of a million millionths. We might apparently avoid all mention of infinitely small quantities, by never carrying our approximations beyond quantities which the senses can appreciate. In geometry, as thus treated, we should never assert two quantities to be equal, but only to be *apparently* equal. Legendre really adopts this mode of treatment in the twentieth proposition of the first book of his Geometry; and it is practically adopted throughout the physical sciences, as we shall afterwards see. But though our fingers, and senses and instruments must stop somewhere, there is no reason why the mind should not go on. We can see that a proof which is only carried through a few steps in fact, might be carried on without limit, and it is this consciousness of no stopping-place which renders Euclid's proof of his 117th proposition so impressive. Try how we will to circumvent the matter, we cannot really avoid the consideration of the infinitely small and the infinitely great. The same methods of approximation which seem confined to the finite, mentally extend themselves to the infinite.

One result of these considerations is, that we cannot possibly adjust two quantities in absolute equality. The suspension of Mahomet's coffin between two precisely equal magnets is theoretically conceivable but practically impossible. The story of the *Merchant of Venice* turns upon the infinite improbability that an exact quantity of flesh could be cut. Unstable equilibrium cannot exist in nature, for it is that which is destroyed by an infinitely small displacement. It might be possible to balance an egg on its end practically, because no egg has a surface of

perfect curvature. Suppose the egg shell to be perfectly smooth, and the feat would become impossible.

I may briefly remind the reader how little we can trust to our unassisted senses in estimating the degree or magnitude of any phenomenon. The eye cannot correctly estimate the comparative brightness of two luminous bodies which differ much in brilliancy; for we know that the iris is constantly adjusting itself to the intensity of the light received, and thus admits more or less light, according to circumstances. The moon which shines with almost dazzling brightness by night is pale and nearly imperceptible while the eye is yet affected by the vastly more powerful light of day. Much has been recorded concerning the comparative brightness of the zodiacal light at different times, but it would be difficult to prove that these changes are not due to the varying darkness at the time, or the different acuteness of the observer's eye. For a like reason it is exceedingly difficult to establish the existence of any change in the form or comparative brightness of nebulæ; the appearance of a nebula greatly depends upon the keenness of sight of the observer, or the accidental condition of freshness or fatigue of his eye. The same is true of lunar observations; and even the use of the best telescope fails to remove this difficulty. In judging of colors, again, we must remember that light of any given color tends to dull the sensibility of the eye for light of the same color.

Nor is the eye when unassisted by instruments of a much better judge of magnitude. Our estimates of the size of minute bright points, such as the fixed stars, are completely falsified by the effects of irradiation. Tycho calculated from the apparent size of the star-disks, that no one of the principal fixed stars could be contained within the area of the earth's orbit. Apart, however, from irradiation or other distinct causes of error our visual estimates of sizes and shapes are often astonishingly incorrect. Artists almost invariably draw distant mountains in ludicrous disproportion to nearer objects, as a comparison of a sketch with a photograph at once shows. The extraordinary apparent difference of size of the sun or moon, according as it is high in the heavens or near the horizon, should be sufficient to make us cautious in accepting the plainest indications of our senses, unassisted by instrumental measurement. As to statements concerning the height of the aurora and the distance of meteors, they

are to be utterly distrusted. When Captain Parry says that a ray of the aurora shot suddenly downwards between him and the land, which was only 3,000 yards distant, we must consider him subject to an illusion of sense.

It is true that errors of observation are more often errors of judgment than of sense. That which is actually seen must be so far truly seen; and if we correctly interpret the meaning of the phenomenon there would be no error at all. But the weakness of the bare senses as measuring instruments, arises from the fact that they import varying conditions of unknown amount, and we cannot make the requisite corrections and allowances as in the case of a solid and invariable instrument.

Bacon has excellently stated the insufficiency of the senses for estimating the magnitudes of objects, or detecting the degrees in which phenomena present themselves. "Things escape the senses," he says, "because the object is not sufficient in quantity to strike the sense: as all minute bodies; because the percussion of the object is too great to be endured by the senses: as the form of the sun when looking directly at it in mid-day; because the time is not proportionate to actuate the sense: as the motion of a bullet in the air, or the quick, circular motion of a firebrand, which are too fast, or the hour-hand of a common clock, which is too slow; from the distance of the object as to place: as the size of the celestial bodies, and the size and nature of all distant bodies; from prepossession by another object: as one powerful smell renders other smells in the same room imperceptible; from the interruption of interposing bodies: as the internal parts of animals; and because the object is unfit to make an impression upon the sense: as the air or the invisible and untangible spirit which is included in every living body."

One remark which we may well make in entering upon quantitative questions, has regard to the great variety and extent of phenomena presented to our notice. So long as we deal only with a simply local question, that question is merely, Does a certain event happen? or, Does a certain object exist? No sooner do we regard the event or object as capable of more and less, than the question branches out into many. We must now ask, How much is it compared with its cause? Does it change when the amount of the cause changes? If so, does it change in the same or opposite direction? Is the change in simple proportion to that

of the cause? If not, what more complex law of connection holds true? This law determined satisfactorily in one series of circumstances may be varied under new conditions, and the most complex relations of several quantities may ultimately be established.

In every question of physical science there is thus a series of steps, the first one or two of which are usually made with ease, while the succeeding ones demand more and more careful measurement. We cannot lay down any invariable series of questions which must be asked from nature. The exact character of the questions will vary according to the nature of the case, but they will usually be of an evident kind, and we may readily illustrate them by examples. Suppose that we are investigating the solution of some salt in water. The first is a purely logical question: Is there solution, or is there not? Assuming the answer to be in the affirmative, we next inquire, Does the solubility vary with the temperature, or not? In all probability some variation will exist, and we must have an answer to the further question, Does the quantity dissolved increase, or does it diminish with the temperature? In by far the greater number of cases salts and substances of all kinds dissolve more freely in the higher temperature of the water; but there are a few salts, such as calcium sulphate, which follow the opposite rule. A considerable number of salts resemble sodium sulphate in becoming more soluble up to a certain temperature, and then varying in the opposite direction. We next require to assign the amount of variation, as compared with that of the temperature, assuming at first that the increase of solubility is proportional to the increase of temperature. Common salt is an instance of very slight variation, and potassium nitrate of very considerable increase with temperature. Accurate observations will probably show, however, that the simple law of proportionate variation is only approximately true, and some more complicated law involving the second, third, or higher powers of the temperature may ultimately be established. All these investigations have to be carried out for each salt separately, since no distinct principles by which we may infer from one substance to another have yet been detected. There is still an indefinite field for further research open; for the solubility of salts will probably vary with the pressure under which the medium is placed; the presence of other salts already dissolved may have effects yet unknown. The researches already effected as

regards the solvent power of water must be repeated with alcohol, ether, carbon bisulphide, and other media, so that unless general laws can be detected, this one phenomenon of solution can never be exhaustively treated. The same kind of questions recur as regards the solution or absorption of gases in liquids, the pressure as well as the temperature having then a most decided effect, and Professor Roscoe's researches on the subject present an excellent example of the successive determination of various complicated laws.

There is hardly a branch of physical science in which similar complications are not ultimately encountered. In the case of gravity, indeed, we arrive at the final law, that the force is the same for all kinds of matter, and varies only with the distance of action. But in other subjects the laws, if simple in their ultimate nature, are disguised and complicated in their apparent results. Thus the effect of heat in expanding solids, and the reverse effect of forcible extension or compression upon the temperature of a body, will vary from one substance to another, will vary as the temperature is already higher or lower, and will probably follow a highly complex law, which in some cases gives negative or exceptional results. In crystalline substances the same researches have to be repeated in each distinct axial direction.

In the sciences of pure observation, such as those of astronomy, meteorology and terrestrial magnetism, we meet with many interesting series of quantitative determinations. The so-called fixed stars, as Giordano Bruno divined, are not really fixed, and may be more truly described as vast, wandering orbs, each pursuing its own path through space. We must then determine separately for each star the following questions:—

1. Does it move?
2. In what direction?
3. At what velocity?
4. Is this velocity variable or uniform?
5. If variable, according to what law?
6. Is the direction uniform?
7. If not, what is the form of the apparent path?
8. Does it approach or recede?
9. What is the form of the real path?

The successive answers to such questions in the case of certain

binary stars have afforded a proof that the motions are due to a central force coinciding in law with gravity, and doubtless identical with it. In other cases the motions are usually so small that it is exceedingly difficult to distinguish them with certainty. And the time is yet far off when any general results as regards stellar motions can be established.

The variation in the brightness of stars opens an unlimited field for curious observation. There is not a star in the heavens concerning which we might not have to determine:—

1. Does it vary in brightness?
2. Is the brightness increasing or decreasing?
3. Is the variation uniform?
4. If not, according to what law does it vary?

In a majority of cases the change will probably be found to have a periodic character, in which case several other questions will arise, such as:—

5. What is the length of the period?
6. Are there minor periods?
7. What is the law of variation within the period?
8. Is there any change in the amount of variation?
9. If so, is it a secular, *i. e.,* a continually growing change, or does it give evidence of a greater period?

Already the periodic changes of a certain number of stars have been determined with accuracy, and the lengths of the periods vary from less than three days up to intervals of time at least 250 times as great. Periods within periods have also been detected.

There is, perhaps, no subject in which more complicated quantitative conditions have to be determined than terrestrial magnetism. Since the time when the declination of the compass was first noticed, as some suppose by Columbus, we have had successive discoveries from time to time of the progressive change of declination from century to century; of the periodic character of this change; of the difference of the declination in various parts of the earth's surface; of the varying laws of the change of declination; of the dip or inclination of the needle, and the corresponding laws of its periodic changes; the horizontal and perpendicular intensities have also been the subject of exact measurement, and have been found to vary with place and time, like the directions of the needle; daily and yearly periodic

changes have also been detected, and all the elements are found to be subject to occasional storms or abnormal perturbations, in which the eleven-year period, now known to be common to many planetary relations, is apparent. The complete solution of these motions of the compass needle involves nothing less than a determination of its position and oscillations in every part of the world at any epoch, the like determination for another epoch, and so on, time after time, until the periods of all changes are ascertained. This one subject offers to men of science an almost inexhaustible field for interesting quantitative research, in which we shall doubtless at some future time discover the operation of causes now most mysterious and unaccountable.

In studying the modes by which physicists have accomplished very exact measurements, we find that they are very various, but that they may perhaps be reduced under the following three classes:—

1. The increase or decrease, in some determinate ratio, of the quantity to be measured, so as to bring it within the scope of our senses, and to equate it with the standard unit, or some determinate multiple or sub-multiple of this unit.

2. The discovery of some natural conjunction of events which will enable us to compare directly the multiples of the quantity with those of the unit, or a quantity related in a definite ratio to that unit.

3. Indirect measurement, which gives us not the quantity itself, but some other quantity connected with it by known mathematical relations.

Several conditions are requisite in order that a measurement may be made with great accuracy, and that the results may be closely accordant when several independent measurements are made.

In the first place the magnitude must be exactly defined by sharp terminations, or precise marks of inconsiderable thickness. When a boundary is vague and graduated, like the penumbra in a lunar eclipse, it is impossible to say where the end really is, and different people will come to different results. We may sometimes overcome this difficulty to a certain extent by observations repeated in a special manner, as we shall afterwards see; but when possible, we should choose opportunities for measurement when precise definition is easy. The moment of occultation

of a star by the moon can be observed with great accuracy, because the star disappears with perfect suddenness; but there are other astronomical conjunctions, eclipses, transits, etc., which occupy a certain length of time in happening, and thus open the way to differences of opinion. It would be impossible to observe with precision the movements of a body possessing no definite points of reference. The colors of the complete spectrum shade into each other so continuously that exact determinations of refractive indices would have been impossible, had we not the dark lines of the solar spectrum as precise points for measurement, or various kinds of homogeneous light, such as that of sodium, possessing a nearly uniform length of vibration.

In the second place, we cannot measure accurately unless we have the means of multiplying or dividing a quantity without considerable error, so that we may correctly equate one magnitude with the multiple or submultiple of the other. In some cases we operate upon the quantity to be measured, and bring it into accurate coincidence with the actual standard, as when in photometry we vary the distance of our luminous body, until its illuminating power at a certain point is equal to that of a standard lamp. In other cases we repeat the unit until it equals the object, as in surveying land, or determining a weight by the balance. The requisites of accuracy now are:—(1) That we can repeat unit after unit of exactly equal magnitude; (2) that these can be joined together so that the aggregate shall really be the sum of the parts. The same conditions apply to subdivision, which may be regarded as a multiplication of subordinate units. In order to measure to the thousandth of an inch, we must be able to add thousandth after thousandth without error in the magnitude of these spaces, or in their conjunction.

To consider the mechanical construction of scientific instruments is no part of my purpose here. I wish to point out merely the general purpose of such instruments, and the methods adopted to carry out that purpose with great precision. In the first place we must distinguish between the instrument which effects a comparison between two quantities, and the standard magnitude which often forms one of the quantities compared. The astronomer's clock, for instance, is no standard of the efflux of time; it serves but to subdivide, with approximate accuracy, the interval of successive passages of a star across the meridian, which it

may effect perhaps to the tenth part of a second, or 1-864,000 part of the whole. The moving globe itself is the real standard clock, and the transit instrument the finger of the clock, while the stars are the hour, minute and second marks, none the less accurate because they are disposed at unequal intervals. The photometer is a simple instrument, by which we compare the relative intensity of rays of light falling upon a given spot. The galvanometer shows the comparative intensity of electric currents passing through a wire. The calorimeter gauges the quantity of heat passing from a given object. But no such instruments furnish the standard unit in terms of which our results are to be expressed. In one peculiar case alone does the same instrument combine the unit of measurement and the means of comparison. A theodolite, mural circle, sextant, or other instrument for the measurement of angular magnitudes has no need of an additional physical unit; for the circle itself, or complete revolution, is the natural unit to which all greater or lesser amounts of angular magnitude are referred.

The result of every measurement is to make known the purely numerical ratio existing between the magnitude to be measured and a certain other magnitude, which should, when possible, be a fixed unit or standard magnitude, or at least an intermediate unit of which the value can be ascertained in terms of the ultimate standard. But though a ratio is the required result, an equation is the mode in which the ratio is determined and expressed. In every measurement we equate some multiple or submultiple of one quantity, with some multiple or submultiple of another, and equality is always the fact which we ascertain by the senses. By the eye, the ear or the touch we judge whether there is a discrepancy or not between two lights, two sounds, two intervals of time, two bars of metal. Often indeed we substitute one sense for the other, as when the efflux of time is judged by the marks upon a moving slip of paper, so that equal intervals of time are represented by equal lengths. There is a tendency to reduce all comparisons to the comparison of space magnitudes, but in every case one of the senses must be the ultimate judge of coincidence or non-coincidence.

Since the equation to be established may exist between any multiples or submultiples of the quantities compared, there naturally arise several different modes of comparison adapted to

different cases. Let p be the magnitude to be measured and q that in terms of which it is to be expressed. Then we wish to find such numbers x and y, that the equation $p = \frac{x}{y} q$ may be true. This equation may be presented in four forms, namely:—

First Form.	Second Form.	Third Form.	Fourth Form.
$p = \frac{x}{y} q$	$p \frac{y}{x} = q$	$py = qx$	$\frac{p}{x} = \frac{p}{y}$

Each of these modes of expressing the same equation corresponds to one mode of effecting a measurement.

When the standard quantity is greater than that to be measured, we often adopt the first mode, and subdivide the unit until we get a magnitude equal to that measured. The angles observed in surveying, in astronomy, or in goniometry are usually smaller than a whole revolution, and the measuring circle is divided by the use of the screw and microscope, until we obtain an angle undistinguishable from that observed. The dimensions of minute objects are determined by subdividing the inch or centimetre, the screw micrometer being the most accurate means of subdivision. Ordinary temperatures are estimated by division of the standard interval between the freezing and boiling points of water, as marked on a thermometer tube.

In a still greater number of cases, perhaps, we multiply the standard unit until we get a magnitude equal to that to be measured. Ordinary measurement by a foot rule, a surveyor's chain, or the excessively careful measurements of a base line of a trigonometrical survey by standard bars, are sufficient instances of this procedure.

In the second case, where $p \frac{y}{x} = q$, we multiply or divide a magnitude until we get what is equal to the unit, or to some magnitude easily comparable with it. As a general rule the quantities which we desire to measure in physical science are too small rather than too great for easy determination, and the problem consists in multiplying them without introducing error. Thus the expansion of a metallic bar when heated from 0 degree

Centigrade to 100 degrees may be multiplied by a train of levers or cog wheels. In the common thermometer the expansion of the mercury, thought slight, is rendered very apparent, and easily measurable by the fineness of the tube, and many other cases might be quoted. There are some phenomena, on the contrary, which are too great or rapid to come within the easy range of our senses, and our task is then the opposite one of diminution. Galileo found it difficult to measure the velocity of a falling body, owing to the considerable velocity acquired in a single second. He adopted the elegant device, therefore, of lessening the rapidity by letting the body roll down an inclined plane, which enables us to reduce the accelerating force in any required ratio. The same purpose is effected in the well-known experiments performed on Attwood's machine, and the measurement of gravity by the pendulum really depends on the same principle applied in a far more advantageous manner. Wheatstone invented a beautiful method of galvanometry for strong currents, which consists in drawing off from the main current a certain determinate portion, which is equated by the galvanometer to a standard current. In short, he measures not the current itself, but a known fraction of it.

In many electrical and other experiments, we wish to measure the movements of a needle or other body, which are not only very slight in themselves, but the manifestations of exceedingly small forces. We cannot even approach a delicately balanced needle without disturbing it. Under these circumstances the only mode of proceeding with accuracy is to attach a very small mirror to the moving body, and employ a ray of light reflected from the mirror as an index of its movements. The ray may be considered quite incapable of affecting the body, and yet by allowing the ray to pass to a sufficient distance, the motions of the mirror may be increased to almost any extent. A ray of light is, in fact, a perfectly weightless finger or index of indefinite length, with the additional advantage that the angular deviation is by the law of reflection double that of the mirror. This method was introduced by Gauss, and is now of great importance; but in Wollaston's reflecting goniometer a ray of light had previously been employed as an index. Lavoisier and Laplace had also used a telescope in connection with the pyrometer.

It is a great advantage in some instruments that they can be

readily made to manifest a phenomenon in a greater or less degree, by a very slight change in the construction. Thus, either by enlarging the bulb or contracting the tube of the thermometer, we can make it give more conspicuous indications of change of temperature. The ordinary barometer, on the other hand, always gives the variations of pressure on one scale. The torsion balance is remarkable for the extreme delicacy which may be attained by increasing the length and lightness of the rod, and the length and thinness of the supporting thread. Forces so minute as the attraction of gravitation between two balls, or the magnetic and diamagnetic attraction of common liquids and gases, may thus be made apparent, and even measured. The common chemical balance, too, is capable theoretically of unlimited sensibility.

The third mode of measurement, which may be called the Method of Repetition, consists in multiplying both magnitudes to be compared until some multiple of the first is found to coincide very nearly with some multiple of the second. If the multiplication can be effected to an unlimited extent, without the introduction of countervailing errors, the accuracy with which the required ratio can be determined is unlimited, and we thus account for the extraordinary precision with which intervals of time in astronomy are compared together.

The fourth mode of measurement, in which we equate submultiples of two magnitudes, is comparatively seldom employed, because it does not conduce to accuracy. In the photometer, perhaps, we may be said to use it; we compare the intensity of two sources of light, by placing them both at such distances from a given surface, that the light falling on the surface is tolerable to the eye, and equally intense from each source. Since the intensity of light varies inversely as the square of the distance, the relative intensities of the luminous bodies are proportional to the squares of their distances. The equal intensity of two rays of similarly colored light may be most accurately ascertained in the mode suggested by Arago, namely, by causing the rays to pass in opposite directions through two nearly flat lenses pressed together. There is an exact equation between the intensities of the beams when Newton's rings disappear, the ring created by one ray being exactly the complement of that created by the other.

The ratio of two quantities can be determined with unlimited

accuracy, if we can multiply both the object of measurement and the standard unit without error, and then observe what multiple of the one coincides, or nearly coincides, with some multiple of the other. Although perfect coincidence can never be really attained, the error thus arising may be indefinitely reduced. For if the equation $py = qx$ be uncertain to the amount e, so that $py = qx \pm e$, then we have $p = q \frac{x}{y} \pm \frac{e}{y}$, and as we are supposed to be able to make y as great as we like without increasing the error e, it follows that we can make $e \div y$ as small as we like, and thus approximate within an inconsiderable quantity to the required ratio $x \div y$.

This method of repetition is naturally employed whenever quantities can be repeated, or repeat themselves, without error of juxtaposition, which is especially the case with the motions of the earth and heavenly bodies. In determining the length of the sidereal day, we determine the ratio between the earth's revolution round the sun, and its rotation on its own axis. We might ascertain the ratio by observing the successive passages of a star across the zenith, and comparing the interval by a good clock with that between two passages of the sun, the difference being due to the angular movement of the earth round the sun. In such observations we should have an error of a considerable part of a second at each observation, in addition to the irregularities of the clock. But the revolutions of the earth repeat themselves day after day, and year after year, without the slightest interval between the end of one period and the beginning of another. The operation of multiplication is perfectly performed for us by nature. If, then, we can find an observation of the passage of a star across the meridian a hundred years ago, that is, of the interval of time between the passage of the sun and the star, the instrumental errors in measuring this interval by a clock and telescope may be greater than in the present day, but will be divided by about 36,524 days, and rendered excessively small. It is thus that astronomers have been able to ascertain the ratio of the mean solar to the sidereal day to the 8th place of decimals (1.00273791 to 1), or to the hundred millionth part, probably the most accurate result of measurement in the whole range of science.

The antiquity of this mode of comparison is almost as great as that of astronomy itself. Hipparchus made the first clear application of it, when he compared his own observations with those of Aristarchus, made 145 years previously, and thus ascertained the length of the year. This calculation may, in fact, be regarded as the earliest attempt at an exact determination of the constants of nature. The method is the main resource of astronomers; Tycho, for instance, detected the slow diminution of the obliquity of the earth's axis, by the comparison of observations at long intervals. Living astronomers use the method as much as earlier ones; but so superior in accuracy are all observations taken during the last hundred years to all previous ones that it is often found preferable to take a shorter interval, rather than incur the risk of greater instrumental errors in the earlier observations.

It is obvious that many of the slower changes of the heavenly bodies must require the lapse of large intervals of time to render their amount perceptible. Hipparchus could not possibly have discovered the smaller inequalities of the heavenly motions, because there were no previous observations of sufficient age or exactness to exhibit them. And just as the observations of Hipparchus formed the starting point for subsequent comparisons, so a large part of the labor of present astronomers is directed to recording the present state of the heavens so exactly that future generations of astronomers may detect changes, which cannot possibly become known in the present age.

The principle of repetition was very ingeniously employed in an instrument first proposed by Mayer in 1767, and carried into practice in the Repeating Circle of Borda. The exact measurement of angles is indispensable, not only in astronomy, but also in trigonometrical surveys, and the highest skill in the mechanical execution of the graduated circle and telescope will not prevent terminal errors of considerable amount. If instead of one telescope the circle be provided with two similar telescopes, these may be alternately directed to two distant points, say, the marks in a trigonometrical survey, so that the circle shall be turned through any multiple of the angle subtended by those marks, before the amount of the angular revolution is read off upon the graduated circle. Theoretically speaking, all error arising from imperfect graduation might thus be indefinitely reduced, being

divided by the number of repetitions. In practice, the advantage of the invention is not found to be very great, probably because a certain error is introduced at each observation in the changing and fixing of the telescopes. It is, moreover, inapplicable to moving objects, like the heavenly bodies, so that its use is confined to important trigonometrical surveys.

The pendulum is the most perfect of all instruments, chiefly because it admits of almost endless repetition. Since the force of gravity never ceases, one swing of the pendulum is no sooner ended than the other is begun, so that the juxtaposition of successive units is absolutely perfect. Provided that the oscillations be equal, one thousand oscillations will occupy exactly one thousand times as great an interval of time as one oscillation. Not only is the subdivision of time entirely dependent on this fact, but in the accurate measurement of gravity, and many other important determinations, it is of the greatest service. In the deepest mine we could not observe the rapidity of fall of a body for more than a quarter of a minute, and the measurement of its velocity would be difficult and subject to uncertain errors from resistance of air, etc. In the pendulum we have a body which can be kept rising and falling for many hours, in a medium entirely under our command, or if desirable in a vacuum. Moreover, the comparative force of gravity at different points, at the top and bottom of a mine, for instance, can be determined with wonderful precision by comparing the oscillations of two exactly similar pendulums with the aid of electric clock signals.

To ascertain the comparative times of vibration of two pendulums, it is only requisite to swing them one in front of the other, to record by a clock the moment when they coincide in swing, so that one hides the other, and then count the number of vibrations until they again come to coincidence. If one pendulum makes m vibrations and the other n, we at once have our equation $pn = qm$; which gives the length of vibration of either pendulum in terms of the other. This method of coincidence, embodying the principle of repetition in perfection, was employed with wonderful skill by Sir George Airy, in his experiments on the Density of the Earth at the Harton Colliery, the pendulums above and below being compared with clocks, which again were compared with each other by electric signals. So exceedingly accurate was this method of observation, as carried out by Sir George Airy.

that he was able to measure a total difference in the vibrations at the top and bottom of the shaft, amounting to only 2 .24 seconds in the twenty-four hours, with an error of less than one hundredth part of a second, or one part in 8,640,000 of the whole day.

The principle of repetition has been elegantly applied in observing the motion of waves in water. If the canal in which the experiments are made be short, say, twenty feet long, the waves will pass through it so rapidly that an observation of one length, as practiced by Walker, will be subject to much terminal error, even when the observer is very skilful. But it is a result of the undulatory theory that a wave is unaltered, and loses no time by complete reflection, so that it may be allowed to travel backwards and forwards in the same canal, and its motion, say, through sixty lengths, or 1,200 feet, may be observed with the same accuracy as in a canal 1,200 feet long, with the advantage of greater uniformity in the condition of the canal and water. It is always desirable, if possible, to bring an experiment into a small compass, so that it may be well under command, and yet we may often by repetition enjoy at the same time the advantage of extensive trial.

One reason of the great accuracy of weighing with a good balance is the fact that weights placed in the same scale are naturally added together without the slightest error. There is no difficulty in the precise juxtaposition of two grammes, but the juxtaposition of two metre measures can only be effected with tolerable accuracy by the use of microscopes and many precautions. Hence the extreme trouble and cost attaching to the exact measurement of a base line for a survey, the risk of error entering at every juxtaposition of the measuring bars, and indefatigable attention to all the requisite precautions being necessary throughout the operation.

In certain cases a peculiar conjunction of circumstances enables us to dispense more or less with instrumental aids, and to obtain very exact numerical results in the simplest manner. The mere fact, for instance, that no human being has ever seen a different face of the moon from that familiar to us, conclusively proves that the period of rotation of the moon on its own axis is equal to that of its revolution round the earth. Not only have we the repetition of these movements during 1,000 or 2,000 years

at least, but we have observations made for us at very remote periods, free from instrumental error, no instrument being needed. We learn that the seventh satellite of Saturn is subject to a similar law, because its light undergoes a variation in each revolution, owing to the existence of some dark tract of land; now this failure of light always occurs while it is in the same position relative to Saturn, clearly proving the equality of the axial and revolutional periods, as Huygens perceived. A like peculiarity in the motions of Jupiter's fourth satellite was similarly detected by Maraldi in 1713.

Remarkable conjunctions of the planets may sometimes allow us to compare their periods of revolution, through great intervals of time, with much accuracy. Laplace in explaining the long inequality in the motions of Jupiter and Saturn, was assisted by a conjunction of these planets, observed at Cairo, towards the close of the eleventh century. Laplace calculated that such a conjunction must have happened on the 31st of October, A. D. 1087; and the discordance between the distances of the planets as recorded and as assigned by theory, was less than one-fifth part of the apparent diameter of the sun. This difference being less than the probable error of the early record, the theory was confirmed, as far as facts were available.

Ancient astronomers often showed the highest ingenuity in turning any opportunities of measurement which occurred to good account. Eratosthenes, as early as 250 B. C., happening to hear that the sun at Syene, in Upper Egypt, was visible at the summer solstice at the bottom of a well, proving that it was in the zenith, proposed to determine the dimensions of the earth by measuring the length of the shadow of a rod at Alexandria on the same day of the year. He thus learned in a rude manner the difference of latitude between Alexandria and Syene and finding it to be about one-fiftieth part of the whole circumference, he ascertained the dimensions of the earth within about one-sixth part of the truth. The use of wells in astronomical observation appears to have been occasionally practiced in comparatively recent times, as by Flamsteed in 1679. The Alexandrian astronomers employed the moon as an instrument of measurement in several sagacious modes. When the moon is exactly half full, the moon, sun and earth are at the angles of a right-angled triangle. Aristarchus measured at such a time the moon's elongation from

the sun, which gave him the two other angles of the triangle, and enabled him to judge of the comparative distances of the moon and sun from the earth. His result, though very rude, was far more accurate than any notions previously entertained, and enabled him to form some estimate of the comparative magnitudes of the bodies. Eclipses of the moon were very useful to Hipparchus in ascertaining the longitude of the stars, which are invisible when the sun is above the horizon. For the moon when eclipsed must be 180° distant from the sun; hence it is only requisite to measure the distance of a fixed star in longitude from the eclipsed moon to obtain with ease its triangular distance from the sun.

In later times the eclipses of Jupiter have served to measure an angle; for at the middle moment of the eclipse the satellite must be in the same straight line with the planet and sun, so that we can learn from the known laws of movement of the satellite the longitude of Jupiter as seen from the sun. If at the same time we measure the elongation or apparent angular distance of Jupiter from the sun, as seen from the earth, we have all the angles of the triangle between Jupiter, the sun, and the earth, and can calculate the comparative magnitudes of the sides of the triangle by trigonometry.

The transits of Venus over the sun's face are other natural events which give most accurate measurements of the sun's parallax, or apparent difference of position as seen from distant points of the earth's surface. The sun forms a kind of background on which the place of the planet is marked, and serves as a measuring instrument free from all the errors of construction which affect human instruments. The rotation of the earth, too, by variously affecting the apparent velocity of ingress or egress of Venus, as seen from different places, discloses the amount of the parallax. It has been sufficiently shown that by rightly choosing the moments of observation the planetary bodies may often be made to reveal their relative distance, to measure their own position, to record their own movements with a high degree of accuracy. With the improvement of astronomical instruments, such conjunctions become less necessary to the progress of the science, but it will always remain advantageous to choose those moments for observation when instrumental errors enter with the least effect.

In other sciences, exact quantitative laws can occasionally be obtained without instrumental measurement, as when we learn the exactly equal velocity of sounds of different pitch, by observing that a peal of bells or a musical performance is heard harmoniously at any distance to which the sound penetrates; this could not be the case, as Newton remarked, if one sound overtook the other. One of the most important principles of the atomic theory was proved by implication before the use of the balance was introduced into chemistry. Wenzel observed, before 1777, that when two neutral substances decompose each other, the resulting salts are also neutral. In mixing sodium sulphate and barium nitrate, we obtain insoluble barium sulphate and neutral sodium nitrate. This result could not follow unless the nitric acid, requisite to saturate one atom of sodium, were exactly equal to that required by one atom of barium, so that an exchange could take place without leaving either acid or base in excess.

An important principle of mechanics may also be established by a simple acoustical observation. When a rod or tongue of metal fixed at one end is set in vibration, the pitch of the sound may be observed to be exactly the same, whether the vibrations be small or great; hence the oscillations are isochronous, or equally rapid, independently of their magnitude. On the ground of theory, it can be shown that such a result only happens when the flexure is proportional to the deflecting force. Thus the simple observation that the pitch of the sound of a harmonium, for instance, does not change with its loudness establishes an exact law of nature.

A closely similar instance is found in the proof that the intensity of light or heat rays varies inversely as the square of the distance increases. For the apparent magnitude certainly varies according to this law; hence, if the intensity of light varied according to any other law, the brightness of an object would be different at different distances, which is not observed to be the case. Melloni applied the same kind of reasoning, in a somewhat different form, to the radiation of heat-rays.

Some of the most conspicuously beautiful experiments in the whole range of science, have been devised for the purpose of indirectly measuring quantities, which in their extreme greatness or smallness surpass the powers of sense. All that we need

to do, is to discover some other conveniently measurable phenomenon, which is related in a known ratio or according to a known law, however complicated, with that to be measured. Having once obtained experimental data, there is no further difficulty beyond that of arithmetic or algebraic calculation.

Gold is reduced by the gold-beater to leaves so thin that the most powerful microscope would not detect any measurable thickness. If we laid several hundred leaves upon each other to multiply the thickness, we should still have no more than 1,100th of an inch at the most to measure, and the errors arising in the superposition and measurement would be considerable. But we can readily obtain an exact result through the connected amount of weight. Faraday weighed 2,000 leaves of gold, each 3⅜ inch square, and found them equal to 384 grains. From the known specific gravity of gold it was easy to calculate that the average thickness of the leaves was 1-282,000 of an inch.

We must ascribe to Newton the honor of leading the way in methods of minute measurement. He did not call waves of light by their right name, and did not understand their nature; yet he measured their length, though it did not exceed the 2,000,000th part of a meter or the one fifty-thousandth part of an inch. He pressed together two lenses of large but known radii. It was easy to calculate the interval between the lenses at any point, by measuring the distance from the central point of contact. Now, with homogeneous rays the successive rings of light and darkness mark the points at which the interval between the lenses is equal to one-half, or any multiple of half a vibration of the light, so that the length of the vibration became known. In a similar manner many phenomena of interference of rays of light admit of the measurement of the wave lengths. Fringes of interference arise from rays of light which cross each other at a small angle, and an excessively minute difference in the lengths of the waves make a very perceptible difference in the position of the point at which two rays will interfere and produce darkness.

Fizeau has recently employed Newton's rings to measure small amounts of motion. By merely counting the number of rings of sodium monochromatic light passing a certain point where two glass plates are in close proximity, he is able to ascertain with the greatest accuracy and ease the change of distance between

these glasses, produced, for instance, by the expansion of a metallic bar, connected with one of the glass plates.

Nothing excites more admiration than the mode in which scientific observers can occasionally measure quantities, which seem beyond the bounds of human observation. We know the *average* depth of the Pacific Ocean to be 14,190 feet, not by actual sounding, which would be impracticable in sufficient detail, but by noticing the rate of transmission of earthquake waves from the South American to the opposite coasts, the rate of movement being connected by theory with the depth of the water. In the same way the average depth of the Atlantic Ocean is inferred to be no less than 22,157 feet, from the velocity of the ordinary tidal waves. A tidal wave again gives beautiful evidence of an effect of the law of gravity, which we could never in any other way detect. Newton estimated that the moon's force in moving the ocean is only one part in 2,871,400 of the whole force of gravity, so that even the pendulum, used with the utmost skill, would fail to render it apparent. Yet, the immense extent of the ocean allows the accumulation of the effect into a very palpable amount; and from the comparative heights of the lunar and solar tides, Newton roughly estimated the comparative forces of the moon's and sun's gravity at the earth.

A few years ago it might have seemed impossible that we should ever measure the velocity with which a star approaches or recedes from the earth, since the apparent position of the star is thereby unaltered. But the spectroscope now enables us to detect and even measure such motions with considerable accuracy, by the alteration which it causes in the apparent rapidity of vibration, and consequently in the refrangibility of rays of light of definite color. And while our estimates of the lateral movements of stars depend upon our very uncertain knowledge of their distances, the spectroscope gives the motions of approach and recess irrespective of other motions excepting that of the earth. It gives in short the motions of approach and recess of the stars relatively to the earth.

The rapidity of vibration for each musical tone, having been accurately determined by comparison with the Siren, we can use sounds as indirect indications of rapid vibrations. It is now known that the contraction of a muscle arises from the period-

ical contractions of each separate fibre, and from a faint sound or susurrus which accompanies the action of a muscle, it is inferred that each contraction lasts for about one 300th part of a second. Minute quantities of radiant heat are now always measured indirectly by the electricity which they produce when falling upon a thermopile. The extreme delicacy of the method seems to be due to the power of multiplication at several points in the apparatus. The number of elements or junctions of different metals in the thermopile can be increased so that the tension of the electric current derived from the same intensity of radiation is multiplied; the effect of the current upon the magnetic needle can be multiplied within certain bounds, by passing the current many times round it in a coil; the excursions of the needle can be increased by rendering it astatic and increasing the delicacy of its suspension; lastly, the angular divergence can be observed, with any required accuracy, by the use of an attached mirror and distant scale viewed through a telescope. Such is the delicacy of this method of measuring heat, that Dr. Joule succeeded in making a thermopile which would indicate a difference of 0°.000114 Centigrade.

A striking case of indirect measurement is furnished by the revolving mirror of Wheatstone and Foucault, whereby a minute interval of time is estimated in the form of an angular deviation. Wheatstone viewed an electric spark in a mirror rotating so rapidly, that if the duration of the spark had been more than one 72,000th part of a second, the point of light would have appeared elongated to an angular extent of one-half degree. In the spark, as drawn directly from a Leyden jar, no elongation was apparent, so that the duration of the spark was immeasurably small; but when the discharge took place through a bad conductor, the elongation of the spark denoted a sensible duration. In the hands of Foucault the rotating mirror gave a measure of the time occupied by light in passing through a few metres of space.

In almost every case a measuring instrument serves, and should serve only as a means of comparison between two or more magnitudes. As a general rule, we should not attempt to make the divisions of the measuring scale exact multiples or submultiples of the unit, but, regarding them as arbitrary marks, should determine their values by comparison with the standard

itself. The perpendicular wires in the field of a transit telescope, are fixed at nearly equal but arbitrary distances, and those distances are afterwards determined, as first suggested by Malvasia, by watching the passage of star after star across them, and noting the intervals of time by the clock. Owing to the perfectly regular motion of the earth, these time intervals give exact determinations of the angular intervals. In the same way, the angular value of each turn of the screw micrometer attached to a telescope, can be easily and accurately ascertained.

When a thermopile is used to observe radiant heat, it would be almost impossible to calculate on *à priori* grounds what is the value of each division of the galvanometer circle, and still more difficult to construct a galvanometer, so that each division should have a given value. But this is quite unnecessary, because by placing the thermopile before a body of known dimensions, at a known distance, with a known temperature and radiating power, we measure a known amount of radiant heat, and inversely measure the value of the indications of the thermopile. In a similar way Dr. Joule ascertained the actual temperature produced by the compression of bars of metal. For having inserted a small thermopile composed of a single junction of copper and iron wire, and noted the deflections of the galvanometer, he had only to dip the bars into water of different temperatures, until he produced a like deflection, in order to ascertain the temperature developed by pressure.

In some cases we are obliged to accept a very carefully constructed instrument as a standard, as in the case of a standard barometer or thermometer. But it is then best to treat all inferior instruments comparatively only, and determine the values of their scales by comparison with the assumed standard.

When a large number of accurate measurements have to be effected, it is usually desirable to make a certain number of determinations with scrupulous care, and afterwards use them as points of reference for the remaining determinations. In the trigonometrical survey of a country, the principal triangulation fixes the relative positions and distances of a few points with rigid accuracy. A minor triangulation refers every prominent hill or village to one of the principal points, and then the details are filled in by reference to the secondary points. The survey of the heavens is effected in a like manner. The ancient astrono-

mers compared the right ascensions of a few principal stars with the moon, and thus ascertained their positions with regard to the sun; the minor stars were afterwards referred to the principal stars. Tycho followed the same method, except that he used the more slowly moving planet Venus instead of the moon. Flamsteed was in the habit of using about seven stars, favorably situated at points all round the heavens. In his early observations the distances of the other stars from these standard points were determined by the use of the quadrant. Even since the introduction of the transit telescope and the mural circle, tables of standard stars are formed at Greenwich, the positions being determined with all possible accuracy, so that they can be employed for purposes of reference by astronomers.

In ascertaining the specific gravities of substances, all gases are referred to atmospheric air at a given temperature and pressure; all liquids and solids are referred to water. We require to compare the densities of water and air with great care, and the comparative densities of any two substances whatever can then be ascertained.

In comparing a very great with a very small magnitude, it is usually desirable to break up the process into several steps, using intermediate terms of comparison. We should never think of measuring the distance from London to Edinburgh by laying down measuring rods, throughout the whole length. A base of several miles is selected on level ground, and compared on the one hand with the standard yard, and on the other with the distance of London and Edinburgh, or any other two points, by trigonometrical survey. Again, it would be exceedingly difficult to compare the light of a star with that of the sun, which would be about thirty thousand million times greater; but Herschel effected the comparison by using the full moon as an intermediate unit. Wollaston ascertained that the sun gave 801,072 times as much light as the full moon, and Herschel determined that the light of the latter exceeded that of *a* Centauri 27,408 times, so that we find the ratio between the light of the sun and star to be that of about 22,000,000,000 to 1.

By far the most perfect and beautiful of all instruments of measurement is the pendulum. Consisting merely of a heavy body suspended freely at an invariable distance from a fixed point, it is most simple in construction; yet all the highest prob-

lems of physical measurement depend upon its careful use. Its excessive value arises from two circumstances.

(1) The method of repetition is eminently applicable to it, as already described.

(2) Unlike other instruments, it connects together three different quantities, those of space, time, and force.

In most works on natural philosophy it is shown, that when the oscillations of the pendulum are infinitely small, the square of the time occupied by an oscillation is directly proportional to the length of the pendulum, and indirectly proportional to the force affecting it, of whatever kind. The whole theory of the pendulum is contained in the formula, first given by Huygens in his *Horologium Oscillatorium*.

$$\text{Time of oscillation} = 3.14159 \sqrt{\frac{\text{length of pendulum}}{\text{force.}}}$$

The quantity 3.14159 is the constant ratio of the circumference and radius of a circle, and is of course known with accuracy. Hence, any two of the three quantities concerned being given, the third may be found; or any two being maintained invariable, the third will be invariable. Thus a pendulum of invariable length suspended at the same place, where the force of gravity may be considered constant, furnishes a measure of time. The same invariable pendulum being made to vibrate at different points of the earth's surface, and the times of vibration being astronomically determined, the force of gravity becomes accurately known. Finally, with a known force of gravity, and time of vibration ascertained by reference to the stars, the length is determinate.

All astronomical observations depend upon the first manner of using the pendulum, namely, in the astronomical clock. In the second employment it has been almost equally indispensable. The primary principle that gravity is equal in all matter was proved by Newton's and Gauss' pendulum experiments. The torsion pendulum of Michell, Cavendish, and Baily, depending upon exactly the same principles as the ordinary pendulum, gave the density of the earth, one of the foremost natural constants. Kater and Sabine, by pendulum observations in different parts of the earth, ascertained the variation of gravity, whence comes a determination of the earth's ellipticity. The laws of electric and

magnetic attraction have also been determined by the method of vibrations, which is in constant use in the measurement of the horizontal force of terrestrial magnetism.

We must not confuse with the ordinary use of the pendulum its application by Newton, to show the absence of internal friction against space, or to ascertain the laws of motion and elasticity. In these cases the extent of vibration is the quantity measured, and the principles of the instrument are different.

It is a matter of some interest to compare the degrees of accuracy which can be attained in the measurement of different kinds of magnitude. Few measurements of any kind are exact to more than six significant figures, but it is seldom that such accuracy can be hoped for. Time is the magnitude which seems to be capable of the most exact estimation, owing to the properties of the pendulum, and the principle of repetition described in previous sections.

As regards short intervals of time, it has already been stated that Sir George Airy was able to estimate one part in 8,640,000, an exactness, as he truly remarks, "almost beyond conception." The ratio between the mean solar and the sidereal day is known to be about one part in one hundred millions, or to the eighth place of decimals.

Determinations of weight seem to come next in exactness, owing to the fact that repetition without error is applicable to them. An ordinary good balance should show about one part in 500,000 of the load. The finest balance employed by M. Stas, turned with one part in 825,000 of the load. But balances have certainly been constructed to show one part in a million, and Ramsden is said to have constructed a balance for the Royal Society, to indicate one part in seven millions, though this is hardly credible. Professor Clerk Maxwell takes it for granted that one part in five millions can be detected, but we ought to discriminate between what a balance can do when first constructed, and when in continuous use.

Determinations of length, unless performed with extraordinary care, are open to much error in the junction of the measuring bars. Even in measuring the base line of a trigonometrical survey, the accuracy generally attained is only that of about one part in 60,000, or an inch in the mile; but it is said that in four measurements of a base line carried out very recently at

Cape Comorin, the greatest error was 0.077 inch in 1.68 mile, or one part in 1,382,400, an almost incredible degree of accuracy. Sir J. Whitworth has shown that touch is every a more delicate mode of measuring lengths than sight, and by means of a splendidly executed screw, and a small cube of iron placed between two flat-ended iron bars, so as to be suspended when touching them, he can detect a change of dimension in a bar, amounting to no more than one-millionth of an inch.

UNITS AND STANDARDS OF MEASUREMENT.

By W. STANLEY JEVONS.

AS we have seen, instruments of measurement are only means of comparison between one magnitude and another, and as a general rule we must assume some one arbitrary magnitude, in terms of which all results of measurement are to be expressed. Mere ratios between any series of objects will never tell us their absolute magnitudes; we must have at least one ratio for each, and we must have one absolute magnitude. The number of ratios n are expressible in n equations, which will contain at least $n + 1$ quantities, so that if we employ them to make known n magnitudes, we must have one magnitude known. Hence, whether we are measuring time, space, density, mass, weight energy, or any other physical quantity, we must refer to some concrete standard, some actual object, which if once lost and irrecoverable, all our measures lose their absolute meaning. This concrete standard is in all cases arbitrary in point of theory, and its selection a question of practical convenience.

There are two kinds of magnitude, indeed, which do not need to be expressed in terms of arbitrary concrete units, since they pre-suppose the existence of natural standard units. One case is that of abstract number itself, which needs no special unit, because any object which exists or is thought of as separate from other objects furnishes us with a unit, and is the only standard required.

Angular magnitude is the second case in which we have a natural unit of reference, namely the whole revolution or *perigon,* as it has been called by Mr. Sandeman. It is a necessary result of the uniform properties of space, that all complete revolutions are equal to each other, so that we need not select any one revolution, but can always refer anew to space itself.

Whether we take the whole perigon, its half, or its quarter, is really immaterial; Euclid took the right angle, because the Greek geometers had never generalized their notions of angular magnitude sufficiently to treat angles of all magnitudes, or of unlimited *quantity of revolution.* Euclid defines a right angle as half that made by a line with its own continuation, which is of course equal to half a revolution, but which was not treated as an angle by him. In mathematical analysis a different fraction of the perigon is taken, namely, such a fraction that the arc or portion of the circumference included within it is equal to the radius of the circle. In this point of view angular magnitude is an abstract ratio, namely, the ratio between the length of arc subtended and the length of the radius. The geometrical unit is then necessarily the angle corresponding to the ratio unity. This angle is equal to about 57°, 17′, 44″.8, or decimally 57°.295779513. . . . It was called by De Morgan the *arcual unit,* but a more convenient name for common use would be *radian,* as suggested by Professor Everett. Though this standard angle is naturally employed in mathematical analysis, and any other unit would introduce great complexity, we must not look upon it as a distinct unit, since its amount is connected with that of the half perigon, by the natural constant 3.14159 . . . usually denoted by the letter π.

When we pass to other species of quantity, the choice of unit is found to be entirely arbitrary. There is absolutely no mode of defining a length, but by selecting some physical object exhibiting that length between certain obvious points — as, for instance, the extremities of a bar, or marks made upon its surface.

Time is the great independent variable of all change — that which itself flows on uninterruptedly, and brings the variety which we call motion and life. When we reflect upon its intimate nature, Time, like every other element of existence, proves to be an inscrutable mystery. We can only say with St. Augustin, to one who asks us what is time, "I know when you do not ask me." The mind of man will ask what can never be answered, but one result of a true and rigorous logical philosophy must be to convince us that scientific explanation can only take place between phenomena which have something in common, and that when we get down to primary notions,

like those of time and space, the mind must meet a point of mystery beyond which it cannot penetrate. A definition of time must not be looked for; if we say with Hobbes, that it is "the phantasm of before and after in motion," or with Aristotle that it is "the number of motion according to former and latter," we obviously gain nothing, because the notion of time is involved in the expressions *before and after, former and latter.* Time is undoubtedly one of those primary notions which can only be defined physically, or by observation of phenomena which proceed in time.

If we have not advanced a step beyond Augustin's acute reflections on this subject, it is curious to observe the wonderful advances which have been made in the practical measurement of its efflux. In earlier centuries the rude sun-dial or the rising of a conspicuous star gave points of reference, while the flow of water from the clepsydra, the burning of a candle, or, in the monastic ages, even the continuous chanting of psalms, were the means of roughly subdividing periods, and marking the hours of the day and night. The sun and stars still furnish the standard of time, but means of accurate subdivision have become requisite, and this has been furnished by the pendulum and the chronograph. By the pendulum we can accurately divide the day into seconds of time. By the chronograph we can subdivide the second into a hundred, a thousand, or even a million parts. Wheatstone measured the duration of an electric spark, and found it to be no more than one 115,200th part of a second, while more recently Captain Noble has been able to appreciate intervals of time not exceeding the millionth part of a second.

When we come to inquire precisely what phenomenon it is that we thus so minutely measure, we meet insurmountable difficulties. Newton distinguished time according as it was *absolute* or *apparent* time, in the following words: — "Absolute, true, and mathematical time, of itself and from its own nature, flows equably without regard to anything external, and by another name is called *duration;* relative, apparent and common time, is some sensible and external measure of duration by the means of motion." Though we are perhaps obliged to assume the existence of a uniformly increasing quantity which we call time, yet we cannot feel or know abstract and absolute time. Duration must be made manifest to us by the recurrence of some

phenomenon. The succession of our own thoughts is no doubt the first and simplest measure of time, but a very rude one, because in some persons and circumstances the thoughts evidently flow with much greater rapidity than in other persons and circumstances. In the absence of all other phenomena, the interval between one thought and another would necessarily become the unit of time, but the most cursory observations show that there are changes in the outward world much better fitted by their constancy to measure time than the change of thoughts within us.

The earth, as I have already said, is the real clock of the astronomer, and is practically assumed as invariable in its movements. But on what ground is it so assumed? According to the first law of motion, every body perseveres in its state of rest or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon. . Rotatory motion is subject to a like condition, namely, that it perseveres uniformly unless disturbed by extrinsic forces. Now uniform motion means motion through equal spaces in equal times, so that if we have a body entirely free from all resistance or perturbation, and can measure equal spaces of its path, we have a perfect measure of time. But let it be remembered that this law has never been absolutely proved by experience; for we cannot point to any body, and say that it is wholly unresisted or undisturbed; and even if we had such a body, we should need some independent standard of time to ascertain whether its motion was really uniform. As it is in moving bodies that we find the best standard of time, we cannot use them to prove the uniformity of their own movements, which would amount to a *petitio principii*. Our experience comes to this, that when we examine and compare the movements of bodies which seem to us nearly free from disturbance, we find them giving nearly harmonious measures of time. If any one body which seems to us to move uniformly is not doing so, but is subject to fits and starts unknown to us, because we have no absolute standard of time, then all other bodies must be subject to the same arbitrary fits and starts, otherwise there would be discrepancy disclosing the irregularities. Just as in comparing together a number of chronometers, we should soon detect bad ones by their going irregularly, as compared with the others, so in nature we detect

disturbed movement by its discrepancy from that of other bodies which we believe to be undisturbed, and which agree nearly among themselves. But inasmuch as the measure of motion involves time, and the measure of time involves motion, there must be ultimately an assumption. We may define equal times, as times during which a moving body under the influence of no force describes equal spaces; but all we can say in support of this definition is, that it leads us into no known difficulties, and that to the best of our experience one freely moving body gives the same results as any other.

When we inquire where the freely moving body is, no perfectly satisfactory answer can be given. Practically the rotating globe is sufficiently accurate, and Thomson and Tait say: "Equal times are times during which the earth turns through equal angles." No long time has passed since astronomers thought it impossible to detect any inequality in its movement. Poisson was supposed to have proved that a change in the length of the sidereal day amounting to one ten-millionth part in 2,500 years was incompatible with an ancient eclipse recorded by the Chaldæans, and similar calculations were made by Laplace. But it is now known that these calculations were somewhat in error, and that the dissipation of energy arising out of the friction of tidal waves, and the radiation of the heat into space, has slightly decreased the rapidity of the earth's rotatory motion. The sidereal day is now longer by one part in 2,700,000, than it was in 720 B. C. Even before this discovery, it was known that invariability of rotation depended upon the perfect maintenance of the earth's internal heat, which is requisite in order that the earth's dimensions shall be unaltered. Now the earth being superior in temperature to empty space, must cool more or less rapidly, so that it cannot furnish an absolute measure of time. Similar objections could be raised to all other rotating bodies within our cognizance.

The moon's motion round the earth, and the earth's motion round the sun, form the next best measure of time. They are subject, indeed, to disturbance from other planets, but it is believed that these perturbations must in the course of time run through their rhythmical courses, leaving the mean distances unaffected, and consequently, by the third Law of Kepler, the periodic times unchanged. But there is more reason than not

to believe that the earth encounters a slight resistance in passing through space, like that which is so apparent in Encke's comet. There may also be dissipation of energy in the electrical relations of the earth to the sun, possibly identical with that which is manifested in the retardation of comets. It is probably an untrue assumption then, that the earth's orbit remains quite invariable. It is just possible that some other body may be found in the course of time to furnish a better standard of time than the earth in its annual motion. The greatly superior mass of Jupiter and its satellites, and their greater distance from the sun, may render the electrical dissipation of energy less considerable than in the case of the earth. But the choice of the best measure will always be an open one, and whatever moving body we choose may ultimately be shown to be subject to disturbing forces.

The pendulum, although so admirable an instrument for subdivision of time, fails as a standard; for though the same pendulum affected by the same force of gravity performs equal vibrations in equal times, yet the slightest change in the form or weight of the pendulum, the least corrosion of any part, or the most minute displacement of the point of suspension, falsifies the results, and there enter many other difficult questions of temperature, friction, resistance, length of vibration, etc.

Thomson and Tait are of opinion that the ultimate standard of chronometry must be founded on the physical properties of some body of more constant character than the earth; for instance, a carefully arranged metallic spring, hermetically sealed in an exhausted glass vessel. But it is hard to see how we can be sure that the dimensions and elasticity of a piece of wrought metal will remain perfectly unchanged for the few millions of years contemplated by them. A nearly perfect gas, like hydrogen, is perhaps the only kind of substance in the unchanged elasticity of which we could have confidence. Moreover, it is difficult to perceive how the undulations of such a spring could be observed with the requisite accuracy. More recently Professor Clerk Maxwell has made the novel suggestion, discussed in a subsequent section, that undulations of light *in vacuo* would form the most universal standard of reference, both as regards time and space. According to this system the unit of time would be the time occupied by one vibration of the

particular kind of light whose wave length is taken as the unit of length.

Next in importance after the measurement of time is that of space. Time comes first in theory, because phenomena, our internal thoughts for instance, may change in time without regard to space. As to the phenomena of outward nature, they tend more and more to resolve themselves into motions of molecules, and motion cannot be conceived or measured without reference both to time and space.

Turning now to space measurement, we find it almost equally difficult to fix and define once and for ever, a unit magnitude. There are three different modes in which it has been proposed to attempt the perpetuation of a standard length.

(1) By constructing an actual specimen of the standard yard or metre, in the form of a bar.

(2) By assuming the globe itself to be the ultimate standard of magnitude, the practical unit being a submultiple of some dimension of the globe.

(3) By adopting the length of the simple seconds pendulum, as a standard of reference.

At first sight it might seem that there was no great difficulty in this matter, and that any one of these methods might serve well enough; but the more minutely we inquire into the details, the more hopeless appears to be the attempt to establish an invariable standard. We must in the first place point out a principle not of an obvious character, namely, that *the standard length must be defined by one single object.* To make two bars of exactly the same length, or even two bars bearing a perfectly defined ratio to each other, is beyond the power of human art. If two copies of the standard metre be made and declared equally correct, future investigators will certainly discover some discrepancy between them, proving of course that they cannot both be the standard, and giving cause for dispute as to what magnitude should then be taken as correct.

If one invariable bar could be constructed and naintained as the absolute standard, no such inconvenience could arise. Each successive generation as it acquired higher powers of measurement, would detect errors in the copies of the standard, but the standard itself would be unimpeached, and would, as it were, become by degrees more and more accurately known. Un-

fortunately to construct and preserve a metre or yard is also a task which is either impossible, or what comes nearly to the same thing, cannot be shown to be possible. Passing over the practical difficulty of defining the ends of the standard length with complete accuracy, whether by dots or lines on the surface, or by the terminal points of the bar, we have no means of proving that substances remain of invariable dimensions. Just as we cannot tell whether the rotation of the earth is uniform, except by comparing it with other moving bodies, believed to be more uniform in motion, so we cannot detect the change of length in a bar, except by comparing it with some other bar supposed to be invariable. But how are we to know which is the invariable bar? It is certain that many rigid and apparently invariable substances do change in dimensions. The bulb of a thermometer certainly contracts by age, besides undergoing rapid changes of dimensions when warmed or cooled through 100° Cent. Can we be sure that even the most solid metallic bars do not slightly contract by age, or undergo variations in their structure by change of temperature. Fizeau was induced to try whether a quartz crystal, subjected to several hundred alternations of temperature, would be modified in its physical properties, and he was unable to detect any change in the coefficient of expansion. It does not follow, however, that, because no apparent change was discovered in a quartz crystal, newly-constructed bars of metal would undergo no change.

The best principle, as it seems to me, upon which the perpetuation of a standard of length can be rested, is that, if a variation of length occurs, it will in all probability be of different amount in different substances. If then a great number of standard metres were constructed of all kinds of different metals and alloys; hard rocks, such as granite, serpentine, slate, quartz, limestone; artificial substances, such as porcelain, glass, etc., etc., careful comparison would show from time to time the comparative variations of length of these different substances. The most variable substances would be the most divergent, and the standard would be furnished by the mean length of those which agreed most closely with each other just as uniform motion is that of those bodies which agree most closely in indicating the efflux of time.

The second method assumes that the globe itself is a body of

invariable dimensions and the founders of the metrical system selected the ten-millionth part of the distance from the equator to the pole as the definition of the metre. The first imperfection in such a method is that the earth is certainly not invariable in size; for we know that it is superior in temperature to surrounding space, and must be slowly cooling and contracting. There is much reason to believe that all earthquakes, volcanoes, mountain elevations, and changes of sea level are evidences of this contraction as asserted by Mr. Mallet. But such is the vast bulk of the earth and the duration of its past existence, that this contraction is perhaps less rapid in proportion than that of any bar or other material standard which we can construct.

The second and chief difficulty of this method arises from the vast size of the earth, which prevents us from making any comparison with the ultimate standard, except by a trigonometrical survey of a most elaborate and costly kind. The French physicists, who first proposed the method, attempted to obviate this inconvenience by carrying out the survey once for all, and then constructing a standard metre, which should be exactly the one ten-millionth part of the distance from the pole to the equator. But since all measuring operations are merely approximate, it was impossible that this operation could be perfectly achieved. Accordingly, it was shown in 1838 that the supposed French metre was erroneous to the considerable extent of one part in 5527. It then became necessary either to alter the length of the assumed metre or to abandon its supposed relation to the earth's dimensions. The French Government and the International Metrical Commission have for obvious reasons decided in favor of the latter course, and have thus reverted to the first method of defining the metre by a given bar. As from time to time the ratio between this assumed standard metre and the quadrant of the earth becomes more accurately known, we have better means of restoring that metre by reference to the globe is required. But until lost, destroyed, or for some clear reason discredited, the bar metre and not the globe is the standard. Thomson and Tait remark that any of the more accurate measurements of the English trigonometrical survey might in like manner be employed to restore our standard yard, in terms of which the results are recorded.

The third method of defining a standard length, by reference

to the seconds pendulum, was first proposed by Huyghens, and was at one time adopted by the English Government. From the principle of the pendulum (p. 186) it clearly appears that if the time of oscillation and the force actuating the pendulum be the same, the length of the pendulum must be the same. We do not get rid of theoretical difficulties, for we must assume the attraction of gravity at some point of the earth's surface, say London, to be unchanged from time to time, and the sidereal day to be invariable, neither assumption being absolutely correct so far as we can judge. The pendulum, in short, is only an indirect means of making one physical quantity of space depend upon two other physical quantities of time and force.

The practical difficulties are, however, of a far more serious character than the theoretical ones. The length of a pendulum is not the ordinary length of the instrument, which might be greatly varied without affecting the duration of a vibration, but the distance from the center of suspension to the center of oscillation. There are no direct means of determining this latter center, which depends upon the average momentum of all the particles of the pendulum as regards the center of suspension. Huyghens discovered that the centers of suspension and oscillation are interchangeable, and Kater pointed out that if a pendulum vibrates with exactly the same rapidity when suspended from two different points, the distance between these points is the true length of the equivalent simple pendulum. But the practical difficulties in employing Kater's reversible pendulum are considerable, and questions regarding the disturbance of the air, the force of gravity, or even the interference of electrical attractions have to be entertained. It has been shown that all the experiments made under the authority of Government for determining the ratio between the standard yard and the seconds pendulum, were vitiated by an error in the corrections for the resisting, adherent, or buoyant power of the air in which the pendulums were swung. Even if such corrections were rendered unnecessary by operating in a vacuum, other difficult questions remain. Gauss' mode of comparing the vibrations of a wire pendulum when suspended at two different lengths is open to equal or greater practical difficulties. Thus it is found that the pendulum standard cannot compete in accuracy and certainty with the simple bar standard, and the method would

only be useful as an accessory mode of restoring the bar standard if at any time again destroyed.

Before we can measure the phenomena of nature, we require a third independent unit, which shall enable us to define the quantity of matter occupying any given space. All the changes of nature, as we shall see, are probably so many manifestations of energy; but energy requires some substratum or material machinery of molecules, in and by which it may be manifested. Observation shows that, as regards force, there may be two modes of variation of matter. As Newton says in the first definition of the Principia, "the quantity of matter is the measure of the same, arising from its density and bulk conjunctly." Thus the force required to set a body in motion varies both according to the bulk of the matter, and also according to its quality. Two cubic inches of iron of uniform quality, will require twice as much force as one cubic inch to produce a certain velocity in a given time; but one cubic inch of gold will require more force than one cubic inch of iron. There is then some new measurable quality in matter apart from its bulk, which we may call *density,* and which is, strictly speaking, indicated by its capacity to resist and absorb the action of force. For the unit of density we may assume that of any substance which is uniform in quality, and can readily be referred to from time to time. Pure water at any definite temperature, for instance that of snow melting under inappreciable pressure, furnishes an invariable standard of density, and by comparing equal bulks of various substances with a like bulk of ice-cold water, as regards the velocity produced in a unit of time by the same force, we should ascertain the densities of those substances as expressed in that of water. Practically the force of gravity is used to measure density; for a beautiful experiment with the pendulum, performed by Newton and repeated by Gauss, shows that all kinds of matter gravitate equally. Two portions of matter then which are in equilibrium in the balance, may be assumed to possess equal inertia, and their densities will therefore be inversely as their cubic dimensions.

Multiplying the number of units of density of a portion of matter, by the number of units of space occupied by it, we arrive at the quantity of matter, or, as it is usually called, the *unit of mass,* as indicated by the inertia and gravity it possesses. To

proceed in the most simple manner, the unit of mass ought to be that of a cubic unit of matter of the standard density; but the founders of the metrical system took as their unit of mass, the cubic centimetre of water, at the temperature of maximum density (about 4° Cent.). They called this unit of mass the *gramme,* and constructed standard specimens of the kilogram, which might be readily referred to by all who required to employ accurate weights. Unfortunately the determination of the bulk of a given weight of water at a certain temperature is an operation involving many difficulties, and it cannot be performed in the present day with a greater exactness than that of about one part in 5000, the results of careful observers being sometimes found to differ as much as one part in 1000.

Weights, on the other hand, can be compared with each other to at least one part in a million. Hence if different specimens of the kilogram be prepared by direct weighing against water, they will not agree closely with each other; the two principal standard kilograms agree neither with each other, nor with their definition. According to Professor Miller the so-called Kilogramme des Archives weighs 15432.34874 grains, while the kilogram deposited at the Ministry of the Interior in Paris, as the standard for commercial purposes, weighs 15432.344 grains. Since a standard weight constructed of platinum, or platinum and iridium, can be preserved free from any appreciable alteration, and since it can be very accurately compared with other weights, we shall ultimately attain the greatest exactness in our measurements of mass, by assuming some single kilogram as a *provisional standard,* leaving the determination of its actual mass in units of space and density for future investigation. This is what is practically done at the present day, and thus a unit of mass takes the place of the unit of density, both in the French and English systems. The English pound is defined by a certain lump of platinum, preserved at Westminster, and is an arbitrary mass, chosen merely that it may agree as nearly as possible with old English pounds. The gallon, the old English unit of cubic measurement, is defined by the condition that it shall contain exactly ten pounds weight of water at 62° Fahr.; and although it is stated that it has the capacity of about 277.274 cubic inches, this ratio between the cubic and linear systems of measurement is not legally enacted, but left open to

investigation. While the French metric system as originally designed was theoretically perfect, it does not differ practically in this point from the English system.

Quite recently Professor Clerk Maxwell has suggested that the vibrations of light and the atoms of matter might conceivably be employed as the ultimate standards of length, time, and mass. We should thus arrive at a *natural system of standards,* which, though possessing no present practical importance, has considerable theoretical interest. "In the present state of science," he says, "the most universal standard of length which we could assume would be the wave-length in vacuum of a particular kind of light, emitted by some widely diffused substance such as sodium, which has well-defined lines in its spectrum. Such a standard would be independent of any changes in the dimensions of the earth, and should be adopted by those who expect their writings to be more permanent than that body." In the same way we should get a universal standard unit of time, independent of all questions about the motion of material bodies, by taking as the unit the periodic time of vibration of that particular kind of light whose wave-length is the unit of length. It would follow that with these units of length and time the unit of velocity would coincide with the velocity of light in empty space. As regards the unit of mass, Professor Maxwell, humorously as I should think, remarks that if we expect soon to be able to determine the mass of a single molecule of some standard substance, we may wait for this determination before fixing a universal standard of mass.

In a theoretical point of view there can be no reasonable doubt that vibrations of light are, as far as we can tell, the most fixed in magnitude of all phenomena. There is as usual no certainty in the matter, for the properties of the basis of light may vary to some extent in different parts of space. But no differences could ever be established in the velocity of light in different parts of the solar system, and the spectra of the stars show that the times of vibration there do not differ perceptibly from those in this part of the universe. Thus all presumption is in favor of the absolute constancy of the vibrations of light — absolute, that is, so far as regards any means of investigation we are likely to possess. Nearly the same considerations apply to the atomic weight as the standard of mass. It is impossible to

prove that all atoms of the same substance are of equal mass, and some physicists think that they differ, so that the fixity of combining proportions may be due only to the approximate constancy of the mean of countless millions of discrepant weights. But in any case the detection of difference is probably beyond our powers. In a theoretical point of view, then, the magnitudes suggested by Professor Maxwell seem to be the most fixed ones of which we have any knowledge, so that they necessarily become the natural units.

In a practical point of view, as Professor Maxwell would be the first to point out, they are of little or no value, because in the present state of science we cannot measure a vibration or weigh an atom with any approach to the accuracy which is attainable in the comparison of standard metres and kilograms. The velocity of light is not known probably within a thousandth part, and as we progress in the knowledge of light, so we shall progress in the accurate fixation of other standards. All that can be said then, is that it is very desirable to determine the wave-lengths and periods of the principal lines of the solar spectrum, and the absolute atomic weights of the elements, with all attainable accuracy, in terms of our existing standards. The numbers thus obtained would admit of the reproduction of our standards in some future age of the world to a corresponding degree of accuracy, were there need of such reference; but so far as we can see at present, there is no considerable probability that this mode of reproduction would ever be the best mode.

Having once established the standard units of time, space, and density or mass, we might employ them for the expression of all quantities of such nature. But it is often convenient in particular branches of science to use multiples or submultiples of the original units, for the expression of quantities in a simple manner. We use the mile rather than the yard when treating of the magnitude of the globe, and the mean distance of the earth and sun is not too large a unit when we have to describe the distances of the stars. On the other hand, when we are occupied with microscopic objects, the inch, the line or the millimetre, become the most convenient terms of expression.

It is allowable for a scientific man to introduce a new unit in any branch of knowledge, provided that it assists precise expression, and is carefully brought into relation with the

primary units. Thus Professor A. W. Williamson has proposed as a convenient unit of volume in chemical science, an absolute volume equal to about 11.2 liters representing the bulk of one gram of hydrogen gas at standard temperature and pressure, or the *equivalent* weight of any other gas, such as 16 grams of oxygen, 14 grams of nitrogen, etc.; in short, the bulk of that quantity of any one of those gases which weighs as many grams as there are units in the number expressing its atomic weight. Hofmann has proposed a new unit of weight for chemists, called a *crith,* to be defined by the weight of one liter of hydrogen gas at 0° C. and 0°.76 mm., weighing about 0.0896 gram. Both of these units must be regarded as purely subordinate units, ultimately defined by reference to the primary units, and not involving any new assumption.

The standard units of time, space, and mass having been once fixed, many kinds of magnitude are naturally measured by units derived from them. From the metre, the unit of linear magnitude follows in the most obvious manner the centiare or square metre, the unit of superficial magnitude, and the liter that is the cube of the tenth part of a metre, the unit of capacity or volume. Velocity of motion is expressed by the ratio of the space passed over, when the motion is uniform, to the time occupied; hence the unit of velocity is that of a body which passes over a unit of space in a unit of time. In physical science the unit of velocity might be taken as one metre per second. Momentum is measured by the mass moving, regard being paid both to the amount of matter and the velocity at which it is moving. Hence the unit of momentum will be that of a unit volume of matter of the unit density moving with the unit velocity, or in the French system, a cubic centimetre of water of the maximum density moving one metre per second.

An accelerating force is measured by the ratio of the momentum generated to the time occupied, the force being supposed to act uniformly. The unit of force will therefore be that which generates a unit of momentum in a unit of time, or which causes, in the French system, one cubic centimetre of water at maximum density to acquire in one second a velocity of one metre per second. The force of gravity is the most familiar kind of force, and as, when acting unimpeded upon any substance, it produces in a second a velocity of 9.80868 . . metres

per second in Paris, it follows that the absolute unit of force is about the tenth part of the force of gravity. If we employ British weights and measures, the absolute unit of force is represented by the gravity of about half an ounce, since the force of gravity of any portion of matter acting upon that matter during one second, produces a final velocity of 32.1889 feet per second or about 32 units of velocity. Although from its perpetual action and approximate uniformity we find in gravity the most convenient force for reference, and thus habitually employ it to estimate quantities of matter, we must remember that it is only one of many instances of force. Strictly speaking, we should express weight in terms of force, but practically we express other forces in terms of weight.

We still require the unit of energy, a more complex notion. The momentum of a body expresses the quantity of motion which belongs or would belong to the aggregate of the particles; but when we consider how this motion is related to the action of a force producing or removing it, we find that the effect of a force is proportional to the mass multiplied by the square of the velocity and it is convenient to take half this product as the expression required. But it is shown in books upon dynamics that it will be exactly the same thing if we define energy by a force acting through a space. The natural unit of energy will then be that which overcomes a unit of force acting through a unit of space; when we lift one kilogram through one metre, against gravity, we therefore accomplish 9.80868 . . units of work, that is, we turn so many units of potential energy existing in the muscles, into potential energy of gravitation. In lifting one pound through one foot there is in like manner a conversion of 32.1889 units of energy. Accordingly the unit of energy will be in the English system, that required to lift one pound through about the thirty-second part of a foot; in terms of metric units, it will be that required to lift a kilogram through about one tenth part of a metre.

Every person is at liberty to measure and record quantities in terms of any unit which he likes. He may use the yard for linear measurement and the liter for cubic measurement, only there will then be a complicated relation between his different results. The system of derived units which we have been briefly considering is that which gives the most simple and natural

relations between quantitative expressions of different kinds, and therefore conduces to ease of comprehension and saving of laborious calculation.

It would evidently be a source of great convenience if scientific men could agree upon some single system of units, original and derived, in terms of which all quantities could be expressed. Statements would thus be rendered easily comparable, a large part of scientific literature would be made intelligible to all, and the saving of mental labor would be immense. It seems to be generally allowed, too, that the metric system of weights and measures presents the best basis for the ultimate system; it is thoroughly established in Western Europe; it is legalized in England; it is already commonly employed by scientific men; it is in itself the most simple and scientific of systems. There is every reason then why the metric system should be accepted at least in its main features.

Ultimately, as we can hardly doubt, all phenomena will be recognized as so many manifestations of energy; and, being expressed in terms of the unit of energy, will be referable to the primary units of space, time, and density. To effect this reduction, however, in any particular case, we must not only be able to compare different quantities of the phenomenon, but to trace the whole series of steps by which it is connected with the primary notions. We can readily observe that the intensity of one source of light is greater than that of another; and, knowing that the intensity of light decreases as the square of the distance increases, we can easily determine their comparative brilliance. Hence we can express the intensity of light falling upon any surface, if we have a unit in which to make the expression. Light is undoubtedly one form of energy, and the unit ought therefore to be the unit of energy. But at present it is quite impossible to say how much energy there is in any particular amount of light. The question then arises,— Are we to defer the measurement of light until we can assign its relation to other forms of energy? If we answer Yes, it is equivalent to saying that the science of light must stand still perhaps for a generation; and not only this science but many others. The true curse evidently is to select, as the provisional unit of light, some light of convenient intensity, which can be reproduced from time to time in the same intensity, and which is defined by phys-

ical circumstances. All the phenomena of light may be experimentally investigated relatively to this unit, for instance that obtained after much labor by Bunsen and Roscoe. In after years it will become a matter of inquiry what is the energy exerted in such unit of light; but it may be long before the relation is exactly determined.

A provisional unit, then, means one which is assumed and physically defined in a safe and reproducible manner, in order that particular quantities may be compared *inter se* more accurately than they can yet be referred to the primary units. In reality the great majority of our measurements are expressed in terms of such provisionally independent units, and even the unit of mass, as we have seen, ought to be considered as provisional.

The unit of heat ought to be simply the unit of energy, already described. But a weight can be measured to the one-millionth part, and temperature to less than the thousandth part of a degree Fahrenheit, and to less therefore than the five-hundred thousandth part of the absolute temperature, whereas the mechanical equivalent of heat is probably not known to the thousandth part. Hence the need of a provisional unit of heat, which is often taken as that requisite to raise one gram of water through one degree Centigrade, that is from 0° to 1°. This quantity of heat is capable of approximate expression in terms of time, space, and mass; for by the natural constant, determined by Dr. Joule, and called the mechanical equivalent of heat, we know that the assumed unit of heat is equal to the energy of 423.55 gram-metres, or that energy which will raise the mass of 423.55 grams through one metre against 9.8.. absolute units of force. Heat may also be expressed in terms of the quantity of ice at 0° Cent., which it is capable of converting into water under inappreciable pressure.

In order to understand the relations between the quantities dealt with in physical science, it is necessary to pay attention to the Theory of Dimensions, first clearly stated by Joseph Fourier, but in later years developed by several physicists. This theory investigates the manner in which each derived unit depends upon or involves one or more of the fundamental units. The number of units in a rectangular area is found by multiplying together the numbers of units in the sides: thus the unit

of length enters twice into the unit of area, which is therefore said to have two dimensions with respect to length. Denoting length by L, we may say that the dimensions of area are $L \times L$ or L^2. It is obvious in the same way that the dimensions of volume or bulk will be L^3.

The number of units of mass in a body is found by multiplying the number of units of volume, by those of density. Hence mass is of three dimensions as regards length, and one as regards density. Calling density D, the dimensions of mass are L^3D. As already explained, however, it is usual to substitute an arbitrary provisional unit of mass, symbolized by M; according to the view here taken we may say that the dimensions of M are L^3D.

Introducing time, denoted by T, it is easy to see that the dimensions of velocity will be $\frac{L}{T}$ or LT^{-1}, because the number of units in the velocity of a body is found by *dividing* the units of length passed over by the units of time occupied in passing. The acceleration of a body is measured by the increase of velocity in relation to the time, that is, we must divide the units of velocity gained by the units of time occupied in gaining it; hence its dimensions will be LT^{-2}. Momentum is the product of mass and velocity, so that its dimensions are MLT^{-1}. The effect of a force is measured by the acceleration produced in a unit of mass in a unit of time; hence the dimensions of force are MLT^{-2}. Work done is proportional to the force acting and to the space through which it acts; so that it has the dimensions of force with that of length added, giving ML^2T^{-2}.

It should be particularly noticed that angular magnitude has no dimensions at all, being measured by the ratio of the arc to the radius as shown. Thus we have the dimensions LL^{-1} or L^0. This agrees with the statement previously made, that no arbitrary unit of angular magnitude is needed. Similarly, all pure numbers expressing ratios only, such as sines and other trigonometrical functions, logarithms, exponents, etc., are devoid of dimensions. They are absolute numbers necessarily expressed in terms of unity itself, and are quite unaffected by the selection of the arbitrary physical units. Angular magnitude, however, en-

ters into other quantities, such as angular velocity, which has the dimensions $\frac{1}{T}$ or T^{-1}, the units of angle being divided by the units of time occupied. The dimensions of angular acceleration are denoted by T^{-2}.

The quantities treated in the theories of heat and electricity are numerous and complicated as regards their dimensions. Thermal capacity has the dimensions ML^{-3}, thermal conductivity, $ML^{-1}T^{-1}$. In Magnetism the dimensions of the strength of pole are $M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}$, the dimensions of field-intensity are $M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}$, and the intensity of magnetization has the same dimensions. In the science of electricity physicists have to deal with numerous kinds of quantity, and their dimensions are different too in the electro-static and the electro-magnetic systems. Thus electro-motive force has the dimensions $M^{\frac{1}{2}}L^{\frac{1}{2}}T^{1}$, in the former, and $M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-2}$ in the latter system. Capacity simply depends upon length in electro-statics, but upon $L^{-1}T^{2}$ in electro-magnetics. It is worthy of particular notice that electrical quantities have simple dimensions when expressed in terms of density instead of mass. The instances now given are sufficient to show the difficulty of conceiving and following out the relations of the quantities treated in physical science without a systematic method of calculating and exhibiting their dimensions. It is only in quite recent years that clear ideas about these quantities have been attained. Half a century ago probably no one but Fourier could have explained what he meant by temperature or capacity for heat. The notion of measuring electricity had hardly been entertained.

Besides affording us a clear view of the complex relations of physical quantities, this theory is specially useful in two ways. Firstly, it affords a test of the correctness of mathematical reasoning. According to the *Principle of Homogeneity*, all the quantities *added* together, and equated in any equation, must have the same dimensions. Hence if, on estimating the dimensions of the terms in any equation, they be not homogeneous, some blunder must have been committed. It is impossible to add a force to a velocity, or a mass to a momentum. Even if the numerical values of the two members of a non-homogeneous equation were equal, this would be accidental, and any alteration

in the physical units would produce inequality and disclose the falsity of the law expressed in the equation.

Secondly, the theory of units enables us readily and infallibly to deduce the change in the numerical expression of any physical quantity, produced by a change in the fundamental units. It is of course obvious that in order to represent the same absolute quantity, a number must vary inversely as the magnitude of the units which are numbered. The yard expressed in feet is 3; taking the inch as the unit instead of the foot it becomes 36. Every quantity into which the dimension length enters positively must be altered in like manner. Changing the unit from the foot to the inch, numerical expressions of volume must be multiplied by $12 \times 12 \times 12$. When a dimension enters negatively the opposite rule will hold. If for the minute we substitute the second as unit of time, then we must divide all numbers expressing angular velocities by 60, and numbers expressing angular acceleration by 60×60. The rule is that a numerical expression varies inversely as the magniture of the unit as regards each whole dimension entering positively, and it varies directly as the magnitude of the unit for each whole dimension entering negatively. In the case of fractional exponents, the proper root of the ratio of change has to be taken.

Having acquired accurate measuring instruments, and decided upon the units in which the results shall be expressed, there remains the question, What use shall be made of our powers of measurement? Our principal object must be to discover general quantitative laws of nature; but a very large amount of preliminary labor is employed in the accurate determination of the dimensions of existing objects, and the numerical relations between diverse forces and phenomena. Step by step every part of the material universe is surveyed and brought into known relations with other parts. Each manifestation of energy is correlated with each other kind of manifestation. Professor Tyndall has described the care with which such operations are conducted.

"Those who are unacquainted with the details of scientific investigation, have no idea of the amount of labor expended on the determination of those numbers on which important calculations or inferences depend. They have no idea of the patience

shown by a Berzelius in determining atomic weights; by a Regnault in determining coefficients of expansion; or by Joule in determining the mechanical equivalent of heat. There is a morality brought to bear upon such matters which, in point of severity, is probably without a parallel in any other domain of intellectual action."

Every new natural constant which is recorded brings many fresh inferences within our power. For if n be the number of such constants known, then $\frac{1}{2}$ (n^2-n) is the number of ratios which are within our powers of calculation, and this increases with the square of n. We thus gradually piece together a map of nature, in which the lines of inference from one phenomenon to another rapidly grow in complexity, and the powers of scientific prediction are correspondingly augmented.

Babbage proposed the formation of a collection of the constant numbers of nature, a work which has at last been taken in hand by the Smithsonian Institution. It is true that a complete collection of such numbers would be almost co-extensive with scientific literature, since almost all the numbers occurring in works on chemistry, mineralogy, physics, astronomy, etc., would have to be included. Still a handy volume giving all the more important numbers and their logarithms, referred when requisite to the different units in common use, would be very useful. A small collection of constant numbers will be found at the end of Babbage's, Hutton's, and many other tables of logarithms, and a somewhat larger collection is given in Templeton's *Millwright and Engineer's Pocket Companion.*

Our present object will be to classify these constant numbers roughly, according to their comparative generality and importance, under the following heads: —

(1) Mathematical constants.
(2) Physical constants.
(3) Astronomical constants.
(4) Terrestrial numbers.
(5) Organic numbers.
(6) Social numbers.

At the head of the list of natural constants must come those which express the necessary relations of numbers to each other. The ordinary Multiplication Table is the most familiar and the most important of such series of constants, and is, theoret-

ically speaking, infinite in extent. Next we must place the Arithmetical Triangle, the significance of which has already been clearly pointed out. Tables of logarithms also contain vast series of natural constants, arising out of the relations of pure numbers. At the base of all logarithmic theory is the mysterious natural constant commonly denoted by e, or ϵ, being equal to the infinite series $1 + \frac{1}{1} + \frac{1}{1.2} + \frac{1}{1.2.3} + \frac{1}{1.2.3.4} + \ldots$, and thus consisting of the sum of the ratios between the numbers of permutations and combinations of 0, 1, 2, 3, 4, etc. things. Tables of prime numbers and of the factors of composite numbers must not be forgotten.

Another vast and in fact infinite series of numerical constants contains those connected with the measurement of angles, and embodied in trigonometrical tables, whether as natural or logarithmic sines, cosines, and tangents. It should never be forgotten that though these numbers find their chief employment in connection with trigonometry, or the measurement of the sides of a right-angled triangle, yet the numbers themselves arise out of numerical relations bearing no special relation to space. Foremost among trigonometrical constants is the well known number π, usually employed as expressing the ratio of the circumference and the diameter of a circle; from π follows the value of the arcual or natural unit of angular value as expressed in ordinary degrees.

Among other mathematical constants not uncommonly used may be mentioned tables of factorials, tables of Bernouilli's numbers, tables of the error function, which latter are indispensable not only in the theory of probability but also in several other branches of science.

It should be clearly understood that the mathematical constants and tables of reference already in our possession, although very extensive, are only an infinitely small part of what might be formed. With the progress of science the tabulation of new functions will be continually demanded, and it is worthy of consideration whether public money should not be available to reward the severe, long-continued, and generally thankless labor which must be gone through in calculating tables. Such labors are a benefit to the whole human race as long as it

shall exist, though there are few who can appreciate the extent of this benefit.

The second class of constants contains those which refer to the actual constitution of matter. For the most part they depend upon the peculiarities of the chemical substance in question, but we may begin with those which are of the most general character. In a first sub-class we may place the velocity of light or heat undulations, the numbers expressing the relation between the lengths of the undulations, and the rapidity of the undulations, these numbers depending only on the properties of the ethereal medium, and being probably the same in all parts of the universe. The theory of heat gives rise to several numbers of the highest importance, especially Joule's mechanical equivalent of heat, the absolute zero of temperature, the mean temperature of empty space, etc.

Taking into account the diverse properties of the elements we must have tables of the atomic weights, the specific heats, the specific gravities, the refractive powers, not only of the elements, but their almost infinitely numerous compounds. The properties of hardness, elasticity, viscosity, expansion by heat, conducting powers for heat and electricity, must also be determined in immense detail. There are, however, certain of these numbers which stand out prominently because they serve as intermediate units or terms of comparison. Such are, for instance, the absolute coefficients of expansion of air, water and mercury, the temperature of the maximum density of water, the latent heats of water and steam, the boiling-point of water under standard pressure, the melting and boiling-points of mercury, and so forth.

The third great class consists of numbers possessing far less generality because they refer not to the properties of matter, but to the special forms and distances in which matter has been disposed in the part of the universe open to our examination. We have, first of all, to define the magnitude and form of the earth, its mean density, the constant aberration of light expressing the relation between the earth's mean velocity in space and the velocity of light. From the earth, as our observatory, we then proceed to lay down the mean distances of the sun, and of the planets from the same center; all the elements of the planetary orbits, the magnitudes, densities, masses, periods of

axial rotation of the several planets are by degrees determined with growing accuracy. The same labors must be gone through for the satellites. Catalogues of comets with the elements of their orbits, as far as ascertainable, must not be omitted.

From the earth's orbit as a new base of observations, we next proceed to survey the heavens and lay down the apparent positions, magnitudes, motions, distances, periods of variation, etc., of the stars. All catalogues of stars from those of Hipparchus and Tycho, are full of numbers expressing rudely the conformation of the visible universe. But there is obviously no limit to the labors of astronomers; not only are millions of distant stars awaiting their first measurements, but those already registered require endless scrutiny as regards their movements in the three dimensions of space, their periods of revolution, their changes of brilliance and color. It is obvious that though astronomical numbers are conventionally called *constant*, they are probably in all cases subject to more or less rapid variation.

Our knowledge of the globe we inhabit involves many numerical determinations, which have little or no connection with astronomical theory. The extreme heights of the principal mountains, the mean elevations of continents, the mean or extreme depths of the oceans, the specific gravities of rocks, the temperature of mines, the host of numbers expressing the meteorological or magnetic conditions of every part of the surface, must fall into this class. Many such numbers are not to be called constant, being subject to periodic or secular changes, but they are hardly more variable, in fact, than some which in astronomical science are set down as constant. In many cases quantities which seem most variable may go through rhythmical changes resulting in a nearly uniform average, and it is only in the long progress of physical investigation that we can hope to discriminate successfully between those elemental numbers which are fixed and those which vary. In the latter case the law of variation becomes the constant relation which is the object of our search.

The forms and properties of brute nature having been sufficiently defined by the previous classes of numbers, the organic world, both vegetable and animal, remains outstanding, and offers a higher series of phenomena for our investigation. All exact knowledge relating to the forms and sizes of living things,

their numbers, the quantities of various compounds which they consume, contain, or excrete, their muscular or nervous energy, etc., must be placed apart in a class by themselves. All such numbers are doubtless more or less subject to variation, and but in a minor degree capable of exact determination. Man, so far as he is an animal, and as regards his physical form, must also be treated in this class.

Little allusion need be made in this work to the fact that man in his economic, sanitary, intellectual, æsthetic or moral relations may become the subject of sciences, the highest and most useful of all sciences. Every one who is engaged in statistical inquiry must acknowledge the possibility of natural laws governing such statistical facts. Hence we must allot a distinct place to numerical information relating to the numbers, ages, physical and sanitary condition, mortality, etc., of different peoples, in short, to vital statistics. Economic statistics, comprehending the quantities of commodities produced, existing, exchanged and consumed, constitute another extensive body of science. In the progress of time exact investigation may possibily subdue regions of phenomena which at present defy all scientific treatment. That scientific method can ever exhaust the phenomena of the human mind is incredible.

THE METRIC SYSTEM.

By ALEXANDER HARVEY.

IN the course of one of those conversational debates which make the official atmosphere of the British House of Lords so genial, that illustrious scientist, Lord Kelvin, ventured on a certain occasion to deplore England's delay in adopting the metric system. He had excellent reasons for deploring that delay, he said, for it had once nearly cost him his life. He was experimenting with a new and ingenious rifle and, having loaded it, was just about to discharge the weapon when his eye caught the table of weights of different dimensions which should have guided him in the use of the piece. Lord Kelvin saw that it was a metric table, and that, consequently, he had put into the rifle too heavy a charge. "Had I not discovered my error in time," he concluded, "I should have been blown to atoms."

The laughter with which this anecdote was received did not, we may rest assured, proceed from the heartlessness of his audience. In fact, it inspired England's Minister of Foreign Affairs, the famous Marquis of Lansdowne, to tell, then and there, another metric system story. An English friend of his, traveling on the continent, sent the prescription of his London physician to be made up by a local chemist. What was his surprise, when the drug arrived, to discover his favorite little pills swollen to the proportion of marbles! And while the Englishman still marveled at this transformation, the local chemist rushed in to explain that the metric system had been taken for granted in compounding the prescription, with the result that each huge pill contained about thirty grains of calomel — "which, I am told," observed the Marquis of Lansdowne, amid the merriment of his auditors, "is considerably more than a grown man's dose."

Anecdotes of this sort carry us curiously back to 850 B. C., more or less, when Dido gained her site for Carthage by measuring the coveted land with a bull's hide, cutting the hide into strips

after she had made the bargain. All ancient history, in fact, records the vicissitudes of weights and measures. Not even the shepherd kings of Egypt were the first to make mad experiments with standards of value and of capacity. The performance of one of them, however, in decreeing that his subjects must accept tin tokens where they had previously accepted only gold ones, is characteristic of antiquity.

But the standards proved stronger than kings — how much stronger may be inferred from the fact that, while the rulers and the religions of Egypt passed into nothingness, the pound and the yard of Egypt are the lineal ancestors of the pound and the yard of our day. The most ancient of Egyptian units of measure, the foot, was the merest fraction over the foot of present day England. The whole ancient world anticipated the modern world by borrowing this foot from the captors of the Jews. The Jews themselves were not behind their contemporaries in the recognition of a universal convenience. A like fate befell the pound. That contemporary standard unit of weight figures under another name — mina — in an inscription on the walls of the great temple of Karnac, telling of the triumphs of Thothmes III., and dating from perhaps 1445 B. C. It was a unit that served two purposes, for it aided in the weight of commodities and in the measure of liquid capacity. Fluids were estimated according to their heaviness by the subjects of this Thothmes. Those accomplished borrowers, the Romans, took over the entire system, modified it to suit their convenience, and handed it on to modern Europe. To the Romans we owe the inch, for they cut the foot of the Egyptians into twelfths in accordance with their peculiar duodecimal system of notation.

Not until we try to get back of the Egyptian pound and yard are we plunged into the vortex of the hot controversy which now rages around the subject of the origin of all weights and measures. There are two theories to deal with, and reams of printed matter have appeared in their support. One party would have us believe that when the prehistoric ancients had hit upon some convenient unit of weight or capacity, they subdivided it for the smaller transactions of every-day life. That idea, say its opponents, is nonsensical. Man's first attempts at weighing were by means of seeds, abundantly placed at his disposal as ideal weights and counters adapted to the primitive state of his intelligence.

Having fixed one diminutive unit of measure in his untaught mind, he evolved a larger one, not by calculation, but from sheer necessity. Such was the germ of that Chaldæan or Babylonian system out of which the Egyptian units ultimately emerged. This "empirical" theory makes short work of the view that the standards of antiquity were scientifically deduced. Those exquisite calculations of the base of the great pyramid as the principal standard, "it being the 500th part of a degree of the meridian, previously ascertained for this purpose," of which we are told by imaginative and eloquent historians, have nothing to do with the case. We blunder egregiously in deriving the non-metric system of modern Europe and America from the astronomical lore of the ancients at the expense of the historical science of the moderns.

The immortal Lilliputian controversy regarding the most available end at which to break an egg was never so vehement, and the dispute as to whether mankind climbed up to a standard or climbed down from one may not be settled at all. The ox and the talent in Homer, and the abundance of gold in ancient Ireland, the significant fact that the gold unit was everywhere equivalent to a cow, and the striking fact that we have ten fingers have been urged by each side in support of its own case. The single point upon which there appears to be general agreement is that the most ancient measures and weights with which civilized man is acquainted arose in Chaldea, Egypt and perhaps Phœnicia. Back to those very standards and weights can be traced those of the twentieth century. The line of descent is through the Egyptians to the Jews, the Asiatics and the Greeks, then to the Romans and then on to the nations of Europe. It seems clear, too, that the proportions of the human frame suggested a variety of units, especially the cubit, so far as measure of length is concerned.

When the Normans went over to England they found the yard, the bushel and the pound flourishing in the Saxon kingdoms. Precisely how the Saxons came by these standards is a matter of dispute, some authorities ascribing the system to the Romans, while others maintain that we are dealing with what, as Lord Dundreary says, "no fellow can find out." Few investigators hesitate to identify the Saxon yard, for instance, with kindred standards in ancient Egypt, but they cannot conjecture how the yard reached Britain. The pound, not to mention other units,

puts just such a riddle to the scientists. And as the pound and the yard had to run the gauntlet of hostile Egyptian kings, we find them struggling with the sumptuary legislation of Tudor and Plantagenet sovereigns. The standard of weights and measures always came out victorious in the long run.

It would be unfair to censure the monarchs of mediæval Europe too severely for their rash interferences with standards of weights and of measure. The chaos confronting them seemed to ache for remedy. There were merchant's pounds, avoirdupois pounds, commercial pounds, troy pounds — sometimes, indeed, two independent sets of them. Yards tended to vary with the climate and liquid measure was modified in accordance not only with locality, but with the character of the fluid. Each branch of trade and commerce claimed the right to set up its own peculiar system. Germany went to extremes, for every petty state had its standards. A foot of four varying lengths plunged merchants into bankruptcy and led to wrangles between the miner and the surveyor, the surveyor and the mechanic. England had such a just grievance against her kings for their arbitrariness in dealing with this sort of a situation that a weights and measures clause was put into Magna Charta. Statutes thundered "that by the consent of the whole realm of England, the measure of our Lord the King was made, viz., an English penny, called a sterling, round and without any clipping, shall weigh thirty-two wheat-corns in the midst of the ear; and twenty pence do make an ounce, and twelve ounces a pound, and eight pounds do make a gallon of wine, and eight gallons of wine do make a bushel, which is the eighth part of a quarter." This glimpse into confusion dates from 1266, when Henry III. sat upon the throne of England. There was at one time, too, a "Tower pound," which so facilitated trickery that Henry VIII. did away with it. "Al maner of golde and sylver shall be wayed by the Pounde Troye," which, he was good enough to explain, "maketh xii. oz. Troye." Monarchs in those days had a habit of bringing home systems of weight and measure from their foreign journeys, like souvenirs, and forcing them upon not too willing subjects. Thus Troy weight seems to have been introduced into England from France as a result of the continental observations of the Black Prince. Thus, too, Peter the Great, haunting English shipyards in quest of ideas, sent back to his empire, in addition to a band of skilled workmen,

the standard foot of the western world, which then officially took the place of the Russian unit of length, the old sagene. The foot is the one feature in which the native Muscovite system agrees with any system in the rest of the world. The notion which the mediæval monarch had of weights and measures was, in a word, as personal as that of which Diedrich Knickerbocker tells in his account of the commerce between the Indians and the Nieuw Netherlands pioneers: "Every Dutchman's hand weighed a pound, and every Dutchman's foot weighed two pounds."

This real or imaginary identification of the king's absolutism with a meteorological chaos at which commerce sickened led to very important consequences in France. The grievances which in that distracted country finally led to the great revolution of 1789 had long pressed with peculiar weight upon the very class which the whirligig of circumstance placed in control — the commercial class. Now, the weights and measures grievance was a commercial grievance. It had the good fortune to connect itself in the popular mind with the anti-monarchical and republican gospel that was so rapidly coming into vogue. The psychological moment had at last arrived for the appearance of a metric system.

But the genesis of the metric system was English rather than French. Some hundred years or so prior to the fall of the Bastile Sir James Stuart, in England, had outlined a decimal standard. Watt, the pioneer of the steam-engine, had been fascinated by this idea, which he urged upon his contemporaries as a happy way of "reducing the weights and measures to speak the same language." The foot, in particular, might be "fixed by the pendulum and a measure of water, and a pound derived from that." Such suggestions lay dormant in the French minds that had absorbed them until the spirit of innovation, brooding in the revolutionary atmosphere of Paris, impregnated them with republican vitality. The Constituent Assembly of 1790, succeeding the States-General of 1789, welcomed the metrical idea as the mathematical symbol of the downfall of tyranny and referred it with enthusiasm to the Academy of Sciences. That delighted body, as eager as the rest of France to prepare for an era of freedom, chose five of its most eminent mathematicians to do justice to the task. They were Condorcet, Laplace, Monge, Borda and Lagrange. "The republic has no use for chemists," said the French revolutionists to one of the most brilliant scientists of that day.

But the republic was to redeem itself by affording this quintette of mathematicians a foretaste of the golden age.

The first point upon which the five eminent thinkers found themselves able to agree concerned the unit of length. It was not to correspond with any unit of length then employed by civilized man. Otherwise, there might be jealousy in every land but that whose standard had been tried and not found wanting. It was next determined that the unit of length should sustain a lucid relation to the unit of weight, while both must be definitely proportioned to the unit of capacity. How was this paragon of a unit to be got hold of?

A theory which was old even then and which attached immense importance to the length of the pendulum beating seconds exploded at once. The five scientists sat down and watched pendulums, estimated their own distance from the equator, and decided that the influence of that imaginary line, increasing as we approach it, would lead only to a variable unit. Next they sought to ascertain precisely what distance a body falls in the first second of its descent, but the law of gravitation gave even less satisfaction in the air than it had previously given in connection with the equator. As a last resort and after disappointments as trying as those which beset the far-reaching calculations of Newton, the patient five fell back upon the one ten-millionth part of a quadrant of the earth's meridian. They might have measured the equator instead of a meridian, but it was suggested that there is only one equator and all nations are not on its route. The mathematicians were anxious to avoid occasion, as we have seen, for jealousy.

It took seven years, however, to complete the trigonometrical measurement of an arc of the earth's meridian, through France from Dunkirk to Barcelona, and a public throbbing in revolution was too impatient to wait. It was urged that no absolutely correct calculation of the kind in progress could possibly be made. The arcs of other meridians had been measured — after a fashion — and they must be made to provide the wonderful unit. But the scientists would not be hurried, and they compromised by sending in a report. It delighted the National Assembly highly. There was much enthusiasm over the decimal scale, rising and falling by tens, and over the terminology, based upon the languages used by the great republican nations of antiquity. The standard of

length was to be called the metre. It was to be exactly one forty-millionth part of the length of the meridian. Prefixes, as required, were to be Greek for lengths greater than the metre and Latin for lengths less than the metre. That is to say, the world must use deci- for tenths, centi- for hundredths, milli- for thousandths, and deka- for tens, hecto- for hundreds, kilo- for thousands. Thus, as the children in France to-day recite:

10 millimetres make 1 centimetre
10 centimetres make 1 decimetre
10 decimetres make 1 metre
10 metres make 1 dekametre
10 dekametres make 1 hectometre
10 hectometres make 1 kilometre (or kilo)

In fact, the vocabulary is the same throughout the entire metric system, and we have but to state lengths in metres, weights in grams and volumes in litres. The decimal prefixes are applied as needed—milligrams, millilitres, and so on. The National Assembly listened to the reading of these details with attentive admiration and passed a law authorizing the mathematicians to continue their ingenious labors. But the illustrious Lavoisier, who literally fell in love with the metric system, was sent to execution by these very revolutionists in the midst of his exertions on behalf of the new standard.

When the five eminent scientists had hit upon the unit of length the Academy told off three eminent scientists to hit upon the unit of weight. This trio — Lefevre, Gineau and Fabbroni — incidentally made an important discovery. They came to the agreement that the unit of weight, for the sake of the academic beauty of the metric system, must be as heavy as that quantity of distilled water, at its maximum density, which would fill the cube of the hundredth part of the metre. In this way perfect interrelation between the weight unit and the length unit would be attained. Distilled water was experimented with upon the assumption that at freezing point its density would be greatest. The water turned out densest not at freezing point, but at four degrees Centigrade above it, and that is why the metric table specifies this temperature. And to-day one may see in a government museum at Paris the tiny cylinder by means of which the three wise men ascertained the weight of its contents in a vacuum.

As regards the unit of capacity, the liter, although its formulas can be set forth in abstruse mathematical style, it is really nothing more complicated than "a measure containing a kilogram weight of distilled water at its maximum density." Distilled water, it may be noted, was used in the determination of units on account of its homogeneity and because its density at any given temperature does not vary. How well the original calculations were made is attested by the fact that no subsequent mathematicians have discredited the foundations of the metric system. Here are some tables (p. 214) of equivalents in our own customary standards of weight and measure as given in the act of Congress which, in 1866, legalized, without making compulsory, the use of the system in our republic.

MEASURES OF LENGTH.

Metric Denominations and Values.		Equivalents in Denominations in Use.	
Myriametre.....	10,000 metres.	6.2137	miles.
Kilometre	1,000 metres.	0.62137	mile, or 3,280 feet 10 inches.
Hectometre	100 metres.	328	feet 1 inch.
Dekametre	10 metres.	393.7	inches.
Metre	1 metre.	39.37	inches.
Decimetre	1-10 of a metre.	3.937	inches.
Centimetre	1-100 of a metre.	0.3937	inch.
Millimetre	1-1000 of a metre.	0.0394	inch.

WEIGHTS.

Metric Denominations and Values.			Equivalents in Denominations in Use.
Names.	Number of Grams.	Weight of What Quantity of Water at Maximum Density.	Avoirdupois Weight.
Miller or tonneau.	1,000,000	1 cubic metre.....	2204.6 pounds.
Quintal	100,000	1 hectolitre.....	220.46 pounds.
Myriagram	10,000	10 litres.....	22.046 pounds.
Kilogram or kilo..	1,000	1 litre.....	2.2046 pounds.
Hectogram	100	1 decilitre.....	3.5274 ounces.
Dekagram	10	10 cubic centimetres.....	0.3527 ounce.
Gram	1	1 cubic centimetre.....	15.432 grains.
Decigram	1-10	1-10 of a cubic centimetre.	1.5432 grains.
Centigram	1-100	10 cubic millimetres.....	0.1543 grain.
Milligram	1-1000	1 cubic millimetre.....	0.0154 grain.

MEASURES OF CAPACITY.

Metric Denominations and Values.			Equivalents in Denominations in Use.	
Names.	Number of Litres.	Cubic Measure.	Dry Measure.	Liquid or Wine Measure.
Kilolitre or stere	1,000	1 cubic metre.....	1.308 cubic yards	264.17 gallons.
Hectolitre	100	1-10 of a cubic metre	2 bush. and 3.35 pecks	26.417 gallons.
Dekalitre	10	10 cubic decimetres..	9.08 quarts.....	2.6417 gallons.
Litre	1	1 cubic decimetre....	0.908 quart.....	1.0567 quarts.
Decilitre	1–10	1-10 of a cubic decimetre	6.1022 cubic inches	0.845 gill.
Centilitre	1–100	10 cubic centimetres.	0.6102 cubic inch	0.338 fluid oz.
Millilitre	1–1000	1 cubic centimetre..	0.061 cubic inch.	0.27 fluid dram

It is easy to leap to the conclusion, after running the eye over tables like these, that a system so pellucid in its clearness must win its way anywhere. But it had a struggle for existence in the land of its birth. It was only provisionally adopted by law in 1793. The beautiful Greek and Latin wording had to wait until the first French republic was three years old before the seal of legal approval was set upon it. It then seemed, indeed, as if the old order had passed forever. Here were metres and grams and litres supplanting the units that had come down from the Egyptians to the people that were doing away with kings and establishing a republican calendar of their own. For the French republic sanctioned the metric system on "18th Germinal, Year III." But the republic was seven years old before the definitive metre, marked on a platinum bar, was deposited in solemn state, amid martial strains, in the Palace of the Archives, followed by a retinue of commissioners from ten approving governments.

But these governments had all been brought under the influence, for the time being, of the new French ideas. Great Britain would not hear of the metric system, emanating, as it did, from a nation which preached the end of kings and the abolition of privilege and caste. Neither could the metres, grams and litres gain the sanction of adherents of the old order in France itself. The metric system, in fact, had "got into politics," and when the great Napoleon tried to effect a compromise between the new measures and the ancient scales there ensued an era of chaos. A fresh generation had appeared by the year 1840, however, and the metric system then came legally into its own. Not an inch of ground has it ever lost, for, with perfections and extensions, its

use is obligatory in all civilized lands to-day except Russia, Great Britain and her colonies, the United States and Japan. In every one of these nations, nevertheless, the use of the metric system has been legalized.

The advantages of the metric system consist primarily in its decimal base, the relation sustained to one another by its units, the simplicity of the terms it employs, the absolute accuracy of its standards, the readiness with which it can be learned, the facility of calculation it affords, its adaptability to the purposes of commerce no less than the purposes of science, and its international character. It has the striking merit, too, of facilitating its own adoption by nations which still cling to the pint and the peck, the pound and the ell. Lord Kelvin, a stout champion of the metric system, avers that whatever difficulty might be caused in shops, in factories or in engineering establishments, were the metric system adopted in England to-morrow, would in a few weeks' time be compensated for by the diminution of labor which the change would produce. As it is, British importers and exporters must reduce yards, tons and hogsheads to metres, grams and litres with an amount of calculation of which the following table gives some idea:

PRECISE EQUIVALENTS.

1	acre	= .40	hectar	.4047
1	bushel	= 35	litres	35.24
1	centimetre	= .39	inch	.3937
1	cubic cent.	= .061	cubic inch	.0610
1	cubic foot	= .028	cubic metre	.0283
1	cubic inch	= 16	cubic cent. †	16.39
1	cubic metre	= 35	cubic feet	35.31
1	cubic metre	= 1.3	cubic yards	1.308
1	cubic yard	= .76	cubic metre	.7645
1	foot	= 30	centimetres	30.48
1	gallon	= 3.8	litres	3.785
1	grain	= .065	gram	.0648
1	gram	= 15	grains	15.43
1	hectar	= 2.5	acres	2.471
1	inch	= 25	millimetres	25.40
1	kilo	= 2.2	pounds	2.205
1	kilometre	= .62	mile	.6214
1	litre	= .91	quart (dry)	.9081
1	litre	= 1.1	quarts (liq'd)	1.057
1	metre	= 3.3	feet	3.281
1	mile	= 1.6	kilometres	1.609
1	millimetre	= .039	inch	.0394
1	ounce (av'd)	= 28	grams	28.35
1	ounce (Troy)	= 31	grams	31.10
1	peck	= 8.8	litres	8.809
1	pint	= .47	litre	.4732
1	pound	= .45	kilo	.4536
1	quart (dry)	= 1.1	litres	1.101
1	quart (liquid)	= .95	litre	.9464
1	sq. centimetre	= .15	sq. inch	.1550
1	sq. foot	= .093	sq. metre	.0929
1	sq. inch	= 6.5	sq. centimetres	6.452
1	sq. metre	= 1.2	sq. yards	1.196

PRECISE EQUIVALENTS.

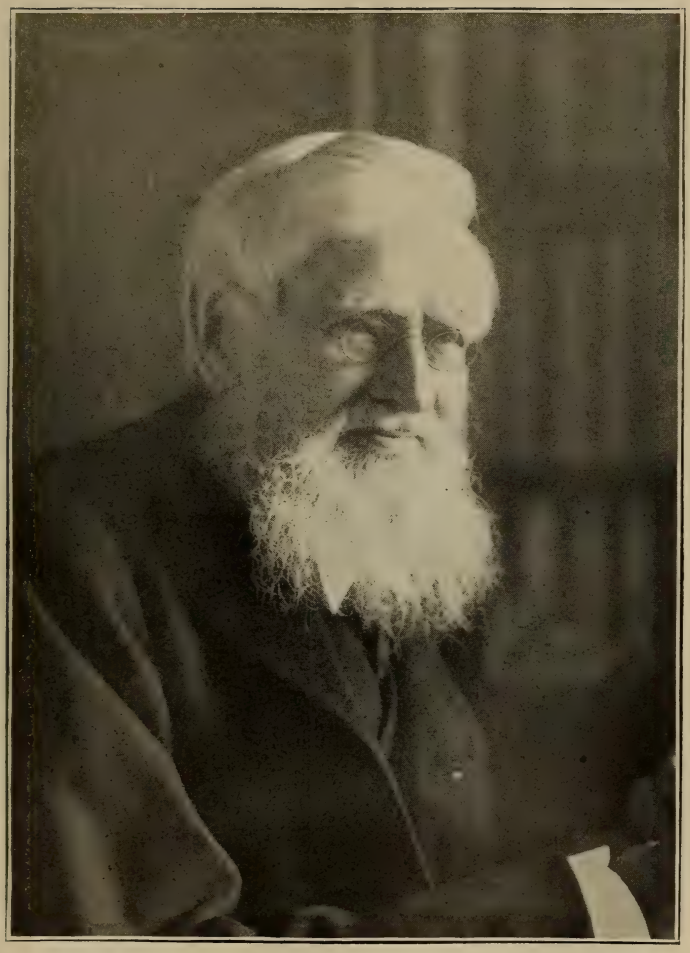
1 sq. metre....	= 11	sq. feet.....	10.76
1 sq. yard.....	= .84	sq. metre.....	.8361
1 t'n (2,000 lbs.)	= .91	metric ton....	.9072
1 t'n (2,240 lbs.)	= 1	metric ton....	1.017
1 ton (metric).	= 1.1	ton (2,000 lbs)	1,102
1 ton (metric).	= .98	ton (2,240 lbs)	.9842
1 yard.....	= .91	metre	.9144

"I was in Germany during the change there," writes Sir W. Ramsay of the days when the metric system was still a novelty in that empire, "and it gave no trouble whatever and was recognized in a week." It has been calculated that about a year would be saved in the school life of every American child were the metric system adopted in the United States. A very determined effort was made in England in 1904 to secure the adoption of the system by Parliament. The Prime Minister of the day, Mr. Balfour, and a former Prime Minister, Lord Rosebery, avowed their preference for the metric system, but it would be too venturesome to predict the triumph of the metre in the British Isles as a thing of the immediate future. In our own country the adoption of the system has been urged by men of learning and distinction for generations. Our own government, in fact, contributes to the support of the metric standard, for it subscribed for one of the two-score or more duplicate sets of the platinum and iridium models distributed among the nations. The United States has also sent delegates to the International Metric Commission.

This body, at its meeting in 1872, was impressed by the fact that if the original standard metre preserved at Paris were destroyed or mislaid, no exact duplicate of it could be made. It is true that the length of this father of metres had been ascertained after seven patient years of measurement of the arc of a meridian. On the other hand, no absolutely exact measurement of this sort is possible to fallible mankind. The original must, therefore, be duplicated or the metric system might be compromised. It was, therefore, determined that every nation using the metric system should be furnished with an exact reproduction of the prototype metre bar. The prototype itself was also duplicated, or, rather, provided with a substitute, and arrangements were even made for a third similar bar maintained at an invariable temperature in a vacuum. Hence it transpires that the metre is to-day legally defined as the distance between two lines on the iridio-platinum bar preserved at the International Bureau of Weights and Measures, which is established at Sevres,

not far from Paris. One of the duplicates is in the Bureau of Standards at Washington.

Beyond such sympathetic association with the metre as this, our government has never gone. This is attributable, doubtless to the fact that we occupy a roomy continent apart from the international action and reaction of the compactly placed nations of continental Europe. We have not been obliged, like the English, to reduce metres to yards and grams to pounds until our patience reached its limits. The growth in our foreign trade must, however, give new point to the suggestions regarding the metric system which appear so often in our consular reports. There will in time spring up as formidable an agitation for the adoption of the metre, gram and litre by the United States as any which agitates England. Such a movement could rest its case upon the judgment of some of the greatest names in our national annals. "The great utility of a standard," wrote President Madison, "fixed in its nature, and founded on the easy rule of decimal proportions, is sufficiently obvious." "Considered merely as a labor-saving device," declared John Quincy Adams of the metric system, "it is a new power offered to man incomparably greater than that which he has acquired by the new agency which he has given to steam. It is in design the greatest invention of human ingenuity since that of printing."



ALFRED RUSSEL WALLACE.

MAN'S PLACE IN THE UNIVERSE.

As Indicated by the New Astronomy.

By ALFRED RUSSEL WALLACE.

TO the early astronomers the earth was the center of the visible universe, sun, moon, planets, and stars all alike revolving around it in more or less eccentric and complex orbits; and all were naturally thought to exist as appendages to our globe, and for the sole use and enjoyment of man — "the sun to rule by day, the moon and the stars to rule by night." But when the Copernican system became established, and it was found that our earth was not specially distinguished from the other planets by any superiority of size or position, it was seen that our pride of place must be given up. And, later, when the discoveries of Newton and of the many brilliant astronomers who succeeded him, together with the ever-widening knowledge derived from the growing power and perfection of the telescope and of improved astronomical instruments, showed us the utter insignificance even of our sun and solar system among the countless hosts of stars and the myriads of clusters and nebulæ, we seemed to be driven to the other extreme, and to be forced to recognize the fact that this vast, stupendous universe could have no special relation to ourselves, any more than to any other of the millions of suns and systems, many of which were probably far grander and more important than ours, and perhaps fitted to be the abode of more highly organized beings.

During the last half century, and perhaps much longer, popular writers have often dealt with the problem of the habitability of the planets by intelligent beings and the probability of other suns being attended by other trains of planets similarly inhabited, and the most diverse and even opposing views have been held as to the inferences to be drawn from these supposed facts. Sir David Brewster held them to be almost essential to an ade-

quate conception of the power and wisdom of the Deity and in some way bound up with the doctrines of Christianity, and this has been the view of many of the teachers of religion. On the other hand, the tendency of all recent astronomical research has been to give us wider views of the vastness, the variety, and the marvelous complexity of the stellar universe, and proportionally to reduce the importance of our little speck of earth almost to the vanishing point, and this has been made use of by the more aggressive among modern skeptics to hold up religious creeds and dogmas to scorn and contempt. They point out the irrationality and absurdity of supposing that the Creator of all this unimaginable vastness of suns and systems, filling, for all we know, endless space, should have any *special* interest in so pitiful a creature as man, the degraded or imperfectly developed inhabitant of one of the smaller planets attached to a second or third rate sun; while that He should have selected this little world for the scene of the tremendous and necessarily unique sacrifice of His Son, in order to save a portion of these "miserable sinners" from the natural consequences of their sins was, in their view, a crowning absurdity too incredible to be believed by any rational being. And it must be confessed that the theologians had no adequate reply to this rude attack; while many of them have felt their position to be untenable, and have renounced the idea of a special revelation and a supreme saviour for the exclusive benefit of so minute and insignificant a speck in the universe.

But, during the last quarter of the past century, the rapidly increasing body of facts and observations, leading to a more detailed and accurate knowledge of stars and stellar systems, have thrown a new and somewhat unexpected light on this very interesting problem of our relation to the universe of which we form a part; and although these discoveries have, of course, no bearing upon the special theological dogmas of the Christian, or of any other religion, they do tend to show that our position in the material universe is special and probably unique, and that it is such as to lend support to the view, held by many great thinkers and writers to-day, that the supreme end and purpose of this vast universe was the production and development of the living soul in the perishable body of man.

The Agnostics and Materialists will no doubt object that the want of all proportion between the means and the end condemns

this theory from its very foundation. But is there any such want of proportion? Given infinite space and infinite time, and there can be no such thing as want of proportion, if the end to be reached were a great and a worthy one and if the particular mode of attaining that end were the best, or, perhaps, even the only possible one; and we may fairly presume that it was so by the fact that it *has* been used, and *has* succeeded. The development of man as a spiritual being, with all his intellectual powers and moral possibilities, is certainly a great end in itself, so great and so noble that if a universe of matter and ether as large as that of which we have now obtained some definite knowledge were required for the work why should it not be used? Of course, I am taking the view of those who believe in some Intelligent Cause at the back of this universe, some creator or creators, designer or designers. For those who take the other view, that matter and ether, with all the laws and forces without which they could not exist for a moment, are, in their essential nature, eternal and self-existent, no such objection is tenable. For the production of life and of man then becomes merely a question of chance — of the right and exact combination of matter and its complex forces occurring after an almost infinite number of combinations that led to nothing. On this view the argument as to our unique position, derived from the discoveries of the New Astronomy, is even more forcible, though hardly so satisfactory, because it also teaches us that if man is a product of blind forces and unconscious laws acting upon non-living matter, then, as he has been produced by physical law, so he will die out by the continued operation of the same laws, against which there is no appeal. These laws of nature have been finely described in the late Grant Allen's striking philosophical poem, which he has entitled "Magdalen Towers," and which was written when he was an undergraduate at Oxford:—

"They care not any whit for pain or pleasure,
That seems to us the sum and end of all,
Dumb force and barren number are their measure,
What shall be shall be though the great earth fall.
They take no heed of man or man's deserving,
Reck not what happy lives they make or mar,
Work out their fatal will unswerv'd, unswerving,
And know not that they are!"

It is the object of the present paper to set forth the nature of the evidence bearing upon man's position in the universe, and to summarize the various lines of research that converge to render it at least a thinkable and rational hypothesis. Although most of the facts and conclusions are well known separately, and have been set forth by both scientific and popular writers, I am not aware that they have been combined, as I now attempt to combine them, or the conclusions drawn from them which seem to me to be the obvious ones.

ARE THE STARS INFINITE IN NUMBER?

It has often been suggested that the stars are infinite in number, and that the stellar universe is therefore infinite in extent; and if the preponderance of evidence pointed in this direction our inquiry would be useless, because as regards infinity there can be no difference of position. In whatever part of it we may be situated, that part can be no nearer the center than any other part. Infinite space has been well defined as a circle, or, rather, a sphere, whose center is everywhere and circumference nowhere.

As the telescope increased in efficiency through the labors of Dollond and Herschel, it was found that every increase of power and of light, due to increased diameter of object-glass or mirror, greatly increased the number of visible stars, and this increase went on with approximate equality of rate till the largest modern telescopes were nearly reached. But, latterly, increased size and power has revealed new stars in a smaller and smaller proportion, indicating that we are approaching the outer limits of the starry system. This conclusion is further enforced by the fact that the numerous dark patches in the heavens, where hardly any stars are visible, and those seen are projected on an intensely dark background, as in the "Coal-sacks" of the southern hemisphere and rifts and channels in the Milky Way itself, continue to present the same features in telescopes of the very highest powers as they do in those of very moderate size. This could not possibly happen if stars were infinite in number, or even if they extended in similar profusion into spaces very much greater than those to which our telescopes can reach, because, in that case, these dark backgrounds would be illuminated by the light of millions of stars so distant as to be separately invisible, as in the case of

the Milky Way itself. The only other explanation would be that the star system is penetrated in several directions by perfectly straight tunnels of enormous length, compared with their diameter, in which no stars exist, and this is considered to be so improbable as to be unworthy of consideration.

The same conclusion is reached by means of that powerful engine of research, the photographic plate. When this is exposed in the focus of a telescope for three hours, a much greater number of stars are revealed than any telescopic vision can detect, but longer exposures add less and less to the number, again indicating that the limit of stars in that direction is nearly reached.

Yet again, the method of counting the stars of the various astronomical magnitudes gives a similar result. At each lesser magnitude the number of stars is about three times greater than that of the next higher magnitude, and this rule applies with tolerable accuracy down to those of the ninth magnitude. The total number of visible stars from the first to the ninth magnitude is about 200,000. Now if this rate of increase continued down to the seventeenth magnitude, the faintest visible in the best modern telescopes would be about 1,400,000,000. But both telescopic observation and photographic charts show that there is nothing approaching this number, it being estimated that the total number thus visible does not exceed 100,000,000 — again proving that as our instruments reach further and further into space, they find a continuous diminution in the number of stars, thus indicating an approach to the outer limits of the stellar universe.

But perhaps the most striking proof of the limited extent of the universe of luminous stars is that dependent on the laws of light. This has been long known to physicists, and it has been very clearly and briefly stated by Professor Simon Newcomb, one of the profoundest mathematical astronomers. He tells us to imagine a series of concentric spheres, each the same distance apart from the first, which includes only the stars visible to the naked eye. The space between each pair of these spheres will be in extent proportional to the squares of the diameters of the spheres that limit it; and as the light we receive from each star is inversely proportional to its distance from us, it follows that if each region were equally strewn with stars of the same average brightness, then we should receive the same amount of light from

each region, the diminution of light from each star being exactly compensated by the vastly greater numbers in each successively larger sphere. Hence it follows that if these concentric spheres were infinite we should receive an infinite amount of light from them, and even if we make an ample allowance for stoppage of light by intervening dark bodies, or by cosmic dust, or by imperfect transparency of the ether, we should at least receive quite as much light from them as the sun gives us at noonday. But the amount we actually receive is so immensely less than this as to prove that the concentric spheres of stars beyond those visible to the naked eye cannot be very numerous. For the total light of all the stars is estimated to be not more than about one-fortieth of moonlight, which is itself only about one five-hundred-thousandth of sunlight. This proof of the limited extent of the stellar universe is, therefore, a very forcible one, and taken in connection with that afforded by telescopic research, as already described, is altogether conclusive.

We have next to consider the facts known as to the distribution and arrangement of the stars, and the conclusions to be drawn therefrom.

THE DISTRIBUTION OF THE STARS IN SPACE.

The first great fact bearing upon this subject is, that a large number of stars are not "fixed," as was universally believed down to the eighteenth century, but that many of them, and probably all, have proper motions of their own. These motions are very small, and can only be detected by observations continued for many years. The most rapid motion yet observed is that of a small star of 6½ magnitude in the Constellation Ursa Major, which moves seven seconds of arc per annum, while others move only this amount in a century, and all but a few less than a second per annum. The proper motions of several thousand stars have now been determined. These motions are in every possible direction, but it has been recently discovered that considerable groups of stars often move in the same direction and at the same rate. The Pleiades exhibit this phenomenon, but much larger groups have the same kind of motion, and this has led to the theory that in certain parts of the heavens there is a star-drift in fixed directions. Our sun is now known to have its own

"proper motion," the direction and rate of which has been determined approximately. This will, of course, produce an apparent movement in all the stars, except those situated exactly in the line of our motion, and the displacement thus caused has to be allowed for in determining the true motion of the stars in space. Should any of the stars be moving obliquely towards us, we shall only perceive that portion of the motion which is at right angles to the direction of the star from us, but the beautiful method of determining motion in the line of sight by means of the spectroscope has overcome this difficulty, and by its means we now know the real motion of many stars, both in direction and velocity, when we have been able to measure their distance from us.

This measurement of the distance of the stars is the most difficult of all the instrumental determinations of modern astronomy, both on account of the extreme remoteness of most of them and because, owing to the motions of the stars themselves, we have no fixed point from which to determine changes of position.

Most people know that by means of a measured base-line the distances of very remote and inaccessible objects can be determined with considerable accuracy, depending upon the length of the base and its careful measurement, and equally upon the extremely accurate measurement of the angles taken at each extremity of the base. It is in this way that the position of mountain peaks is determined, as well as the distances across narrow seas, while all civilized countries have been trigonometrically surveyed in this manner.

In the case of the stars the base-line used is the diameter of the earth's orbit, more than 180,000,000 of miles. Every six months we are at opposite ends of this base, and if we had any absolutely fixed point in the heavens, in the right position, from which to take our angles, we could in this way determine the distance of some of the stars. But as almost all the stars are moving at various rates and in various directions, as our sun itself is moving, and as the proper motions of the stars can only be determined in relation to other stars, there is everywhere a complication of opposing motions, and nowhere the assured fixity we require for such delicate measurements. But notwithstanding all these difficulties, astronomers have by various ingenious methods now measured the distances of a number of stars with considerable precision, notwithstanding the failures of their prede-

cessors for nearly two centuries. The nearest of all the stars are so remote that the distance between the earth and the sun as seen from the star would subtend an angle of considerably less than one second of arc, while most of those measured are so excessively distant that this angle is often one-tenth of a second or even considerably less. To understand how small a quantity this is and what a distance it implies, it may be stated that, viewed at a mile distant, the small letter o in this page would subtend an angle of about one-tenth of a second. From a star of an average distance from us, therefore, the earth and sun, if they could be seen, would appear only as far apart as the opposite sides of the letter o when a mile away from us. But stars twice as far as these have been measured, it is believed with some degree of certainty, and the distances of about sixty stars have now been satisfactorily ascertained.

It was long supposed that the brightest stars were the nearest to us, but it is now known that there is little or no relation between brightness or magnitude and distance. The nearest star yet measured is, indeed, a very bright one in the Southern Hemisphere, Alpha Centauri, but one almost as near, 61 Cygni, is of the fifth magnitude only, and another still nearer in the constellation, Piscis Australis, is of the seventh magnitude. Other stars of the first magnitude which have had their distances measured have a parallax of considerably less than one-tenth of a second, and are, therefore, among the remoter stars.

The true relation, as was long suspected theoretically, is between proper motion and distance, those which move fastest being nearest to us. It is as if, from a mountain-top, we observed ships at sea from two or three miles to forty or fifty miles distant, and kept a record of their angular movements. All might be really moving at not very different speeds — from five to perhaps fifteen or twenty miles an hour, yet while some would appear to move rapidly others would seem to be almost stationary, and this would depend almost entirely on their distance from the observer. So with the stars. All may have, and probably have, real motions which do not differ very greatly in rapidity, but only in those which are comparatively near us can we detect any motion at all. This theoretical conclusion being confirmed by all the stars, whose distances have been measured, we have a most valuable and trustworthy means of ascertaining their compara-

tive distances from us, since those whose proper motions are either exceedingly small or cannot be detected at all, are certainly very much farther from us than those which have well-marked and large, proper motions. It is by such indications that we are enabled to arrive at some definite conclusions as to the real form and structure of the stellar universe, as we will proceed to show.

THE GALAXY, OR MILKY WAY.

By far the most prominent feature in the starry heavens is that vast irregular nebulous ring which in all ages has attracted the attention and excited the admiration of observers. This great ring divides the whole heavens into two hemispheres, making an angle of about 63° with the equinoctial, so that portions of it pass not far from the North and South Poles. Its nebulosity is now believed to be almost wholly due to the massing together of myriads of minute stars, since each increase in the power of the telescope shows more and more of these stars, while the best photographic plates show them everywhere closely packed, but still with a luminous haze between them, indicating yet more stars beyond.

But beside these minute stars, which give us the cloudy or milky appearance, it is found that stars of all degrees of brilliancy are more numerous in the Milky Way and in its vicinity than elsewhere. The two poles of the Galaxy are the regions where stars are scantiest. Each 15° nearer to it, they increase in numbers, at first slowly, then more rapidly, till we reach its borders. The following series of numbers give the average number of stars in a square of 15′ at each 15° from the pole of the Galaxy, as determined by Sir John Herschel 4—5—8—13—24—53.

Later observations have fully confirmed this, while it has been shown by the late Mr. Proctor that all stars down to the tenth magnitude, more than 324,000 in number, when carefully mapped, mark out the Milky Way in all its details by their greater density. Later still, the Italian astronomer, Schiaparelli, by using all the materials now available, arrives at the same result, and Professor S. Newcomb, of Washington, after a close examination of his maps, assures us that the Milky Way can be fairly traced out by the region of maximum agglomeration of stars.

These facts lead to the conclusion that the Galaxy is a vast

annular agglomeration of stars forming a great circle round the heavens, although in places very irregular, being split in two for about one-third of its circumference, and being, besides, full of irregular dark streaks and patches, where the most powerful telescopes show very few stars, so that, as Sir John Herschel says, we are irresistibly led to the conclusion that, in those regions, "we see fairly through the starry stratum"; and this is further shown by the fact that in these parts "the ground of the heavens seen between the stars is for the most part perfectly dark, which would not be the case if multitudes of stars, too minute to be individually discernible, existed beyond." This great ring is, therefore, evidently not very much extended in the direction of its own plane — that is, the ring is not flat or greatly compressed (as is Saturn's ring, for example), or we should nowhere see through it.

But what is more important is, that we must be situated not *in* any part of it as was once supposed, but at or near the very central point in the plane of the ring, that is, nearly equally distant from every part of it. This must be the case, because from any other position the ring would not appear to us so symmetrical as it does. If we were much nearer to one side of it than to the other, the nearer side would appear broader, the more remote side narrower, and these two directions would show a decided difference in the numbers of the visible stars. Sir John Herschel, indeed, thought the southern portion was nearer to us than the northern, because of its greater *brightness,* which, he says, is very striking, and conveys strongly the *idea* of greater proximity. But this may be deceptive, because the whole Milky Way shows great irregularities and variations in brightness, and it is a remarkable fact that the portions near the North and South Poles are *both* equally narrow, while the parts 90° from them are *both* very broad, rather suggesting equality of distance in all directions. Nearness would be indicated by a widening out of stars of all magnitudes, not necessarily by any general increase of brilliancy. The facts, therefore, seem to show that we are about equally distant from all parts of the Milky Way.

Very important, however, is Sir John Herschel's testimony to the close correspondence of the Galaxy as a whole to a great circle. He tells us that, following the line of its greatest brightness, it conforms, as nearly as may be, to that of a great circle

inclined about 63° to the equinoctial, and cutting that circle in R.A. 6h. 47m., and 18h. 47m., while its poles are in R.A. 12h. 47 m. N. Decl., 27°, and R.A. 0h. 47m., S. Decl., 27°. He therefore determines it, *by the figures he gives,* to lie in an *exact* great circle as seen from the earth, as nearly as so irregular an object can be defined. But neither he nor any other astronomer, so far as I am aware, makes any remark on the extraordinary nature of this fact, which proves that we are placed *exactly* in the plane of the medial line of the ring. The fact of the Galaxy forming a great circle as seen from the earth being so familiar, no one seems to have thought it worth while to ask why it is so. If we could look at such a fact from the outside, as it were, we should certainly impute it to some causal connection between our system and the Galaxy. But before speculating what this relation may mean we must consider another point of equal importance in our relation to the system of stars.

OUR STAR CLUSTER.

It has long been observed that the brighter stars seem scattered over the whole heavens, with no special abundance in or near the Milky Way, and this was thought to be due to their being much nearer to us. It is now known, however, that brightness is no indication of nearness, so that this fact has little significance. But, as we have seen, we do possess a real test of nearness in the amount of the proper motion of stars, and this leads us to a very definite and most suggestive conclusion. For the stars which are nearest to us, judged by this test, not only have no apparent relation to the Milky Way, but are spread over *every* part of the heavens with tolerable uniformity. The most recent examination of this class of stars is by Professor S. Newcomb, who states the result in the following words: — "If we should blot out from the sky all the stars having no proper motion large enough to be detected, we should find remaining stars of all magnitudes, but they would be scattered almost uniformly over the sky, and show no tendency towards the Milky Way."

Professor Kapteyn, of Groningen, appears to have been the first to draw the obvious conclusion from these facts that these nearer stars spread around us in *every* direction, constitute a globular mass, which he termed the "solar cluster," nearly con-

centric with the Milky Way, and that our Sun is "deeply immersed" in this cluster.

Other astronomers have adopted this view, which seems to be almost indisputable if the facts are as stated. For, if the cluster were *not* globular, its component stars would not appear to be so uniformly spread over the *whole* heavens; and if our sun were *not* situated at or near its center, but much nearer to one side of it than to the other, then we should inevitably find the stars of this type (those with measurable proper motions) much more numerous in one direction than in a direction exactly opposite. But, although there may be some irregularities in their distribution, it has not been pointed out that there is any such regular inequality as this, and if there is not, then we must be situated very near indeed to the center of this "solar cluster."

The results so far reached by astronomers as the direct logical conclusion from the whole mass of facts accumulated by means of those powerful instruments of research which have given us the New Astronomy is that our Sun is one of the central orbs of a globular star-cluster, and that this star-cluster occupies a nearly central position in the exact plane of the Milky Way. But I am not aware that any writer has taken the next step, and combining these two conclusions has stated definitely that our Sun is thus shown to occupy a position very near to, if not actually at, the center of the whole visible universe, and therefore, in all probability, in the *center* of the *whole material universe.*

This conclusion is, no doubt, a startling one, and all kinds of objections will be made against its being accepted as a proved fact. And yet I am not acquainted with any great inductive result of modern scence that has been arrived at so gradually, so legitimately, by means of so vast a mass of precise measurement and observation, and by such wholly unprejudiced workers. It may not be proved with minute accuracy as regards the actual mathematical center. That is not of the least importance. But that it is substantially correct in the terms I have stated there seems no good reason to doubt, and I therefore hold it to be right and proper to have it so stated and provisionally accepted, until further accumulations of evidence may show to what extent it requires modification.

This completes the first part of our inquiry; but an equally important part remains to be considered — our position in the

Solar System itself as regards adaptability for organic life. Here, too, I am not aware that the whole facts have been sufficiently considered, yet they are facts that indicate our position in this respect to be, in all probability, as central and unique as is that of our Sun in the stellar universe.

THE EARTH AS ADAPTED FOR LIFE.

Among the many writers who have more or less seriously discussed the question of the adaptability of other planets for the development of organic life, and of the higher forms of intellectual beings, I have not met with any who have considered the problem in all its bearings. They have usually been content to show that certain planets *may possibly* be *now* in a condition to support life in forms not very dissimilar from those upon our earth; but they have never adequately considered the precedent question: Could such life have originated and have been developed upon these planets? This is the real *crux* of the problem, and I believe that a full consideration of the required conditions will satisfy us that, so far as we can judge, no other planet can fulfil them. Let us, therefore, consider what these conditions are.

The earlier writers on this subject could give free play to their imaginations and overcome difficulties of temperature, moisture, etc., by supposing that in other worlds there might be other elements which had different properties from any we possess, and which might render life possible under conditions very unlike those which are essential here. But the revelations of spectrum-analysis have shown us the unity of the constitution of matter throughout the whole material universe, so that not only are the planets of the solar system all composed of the same elements, but that the farthest stars and remotest nebulæ alike consist of the very same elements with which we are so familiar, while the same physical and chemical laws undoubtedly prevail. We may be confident, therefore, that wherever organized life may have developed, it must be built up out of the same fundamental elements as here on earth.

The essential features of the structure of organized beings are continuous growth and repair of tissues, nutrition by the absorption of dead or living matter from without, and its transformation into the various unstable compounds of which their bodies are

built up. For these purposes a double system of circulation, gaseous and liquid, has to be constantly in operation, and this is carried on by means of minute tubular or cellular vessels which permeate every part of the body. These wonderfully complex and exquisitely adjusted circulating systems are entirely dependent on the continuous maintenance of a very narrow range of temperatures somewhere between the extremes of the boiling and the freezing points of water, but really within much narrower limits, since if the whole of the water at any time became solidified, all the higher forms of life would be destroyed, while a temperature very much below the boiling point, if permanently maintained, would be almost equally detrimental.

When we consider that the temperature of space is about —273° C., while that of the outer surfaces of the sun is about 9,000° C., we realize what a combination of favorable conditions must exist to preserve on the surface of a planet a degree of heat which shall never for any considerable time fall below 0° C., or rise above, say, 75° C., and that these narrow limits must be *continuously maintained,* not for hundreds or thousands only, but for millions, perhaps for *hundreds of millions of years,* if life is to be developed there. It is the maintenance of this comparatively uniform surface temperature for such enormous periods — during, in fact, the whole time covered by the geological record — that most writers have overlooked as among the necessary conditions for the development of the higher forms of life on a planet; and this omission vitiates all their reasoning, since they have to show not only that the requisite conditions of temperature *may* exist now, but that there is even a probability that they have existed, or will exist, for a sufficiently extended period to allow of the development of a complex system of organic life comparable with our own. Let us then enumerate the chief favorable conditions which in their combination appear to have rendered this development possible on our earth. These are:—

(1) A distance from the sun such as to keep up the temperature of the soil to the required amount, by sun-heat alone, and to evaporate sufficient water to produce clouds, rain and a system of river circulation.

(2) An atmosphere of sufficient extent and density to allow of the production and circulation of aqueous vapor in the form of clouds, mists and dews, and to serve also as an equalizer of sun-

heat during day and night, winter and summer, and also between the tropical and temperate zones. This amount of atmosphere is held to be largely dependent upon the mass of a planet, and this one feature alone probably renders Mars quite unsuitable, since its mass is less than one-eighth that of the earth.

(3) The very large proportion of the surface covered by deep oceans so that they surround and interpenetrate the land, and by their tides and currents keep up a continuous circulation, and are thus the chief agents in the essential equalization of temperatures. This, again, is largely dependent on our possessing so large a satellite, capable of producing a regular, but not excessive, tidal action. The want of such a satellite may alone render Venus quite unsuitable for the development of high forms of life, even if other conditions were more favorable, which seems in the highest degree improbable.

(4) The enormous average depth of these oceans, so that the bulk of water they contain is about thirteen times that of the land which rises above their level. This indicates that they are *permanent features of the earth's surface,* thus ensuring the maintenance of continuous land-areas and of uniform temperatures during the whole period of the development of life upon the earth.*

It is extremely improbable that this remarkable condition obtains in any other planet.

(5) Lastly, one of the most peculiar and least generally considered features of our earth, but one which is also essential to the development and maintenance of the rich organic life it possesses, is the uninterrupted supply of atmospheric dust, which is now known to be necessary for the production of rain clouds and beneficial rains and mists, and without which the whole course of meteorological phenomena would be so changed as to endanger the very existence of a large portion of the life upon the earth. How and why this is so is fully explained in my *Wonderful Century.* Now, the chief portion of this fine dust, distributed through the upper atmosphere, from the equator to the poles, with wonderful uniformity, is derived from those great terrestrial features which are often looked upon as the least essential, and

* The evidence which demonstrates this permanence is set forth in my *Island Life,* Chap. VI., and enforced by additional arguments in my *Studies Scientific and Social,* Vol. I., Chap. 2.

even as blots and blemishes on the fair face of nature — deserts and volcanoes. Most persons, no doubt, think they could both be very well spared, and that the earth would be greatly improved, from a human point of view, if they were altogether abolished. Yet it is almost a certainty that the consequences of doing so would be to render the earth infinitely less enjoyable, and, perhaps, altogether uninhabitable by man. We must, therefore, reckon a due proportion of deserts and active volcanoes, with sufficiently constant winds to distribute the dust from them, as among the permanent essentials of a globe fitted for the development of intelligent life. This utility of deserts and volcanoes is, I think, now stated for the first time.

Now, if we consider that these five distinct conditions, or sets of conditions, many of them dependent on a delicate balance of forces acting at the origin of our planet, appear to be absolutely essential for the existence of high types of organic life, we shall at once see how peculiar and unique is our place and condition within the Solar System, since we know, with almost complete certainty, that they do *not* all co-exist in any of the other planets. And when we consider further, that even if they do happen to exist now, that would be nothing to the purpose unless we had reason to believe that they had also existed, as with us, *in unbroken continuity,* for scores, or, perhaps, hundreds of millions of years. All the evidence at our command goes to assure us that our earth alone in the Solar System has been from its very origin adapted to be the theatre for the development of organized and intelligent life. Our position within that system is, therefore, as central and unique as that of our Sun in the whole stellar universe.

But, it may be asked, even if it be conceded that both by position, by size, and by its combination of physical features, we really do stand alone in the Solar System in our adaptation for the development of intelligent life, in what way can the position of our Sun at or near the center of the stellar universe, as it certainly appears to be, affect that adaptation? Why should not one of the Suns on the confines of the Milky Way, or in any other part of it, possess planets as well adapted as we are to develop high forms of organic life?

These are questions which involve the most difficult problems in mathematical physics, and only our greatest thinkers, possess-

ing the highest mathematical and physical knowledge, could be expected to give any adequate answer to them. In the meantime I will briefly indicate what seems to me to be the probable nature of the reply. Accepting the proof astronomers have given us, that so far from the material universe of which our Sun forms a part extending infinitely into space, we can actually *see* beyond its outer boundaries, and can even approximately give a maximum limit to its magnitude, we are confronted with the problem, of how a limited universe of matter and ether, with the motions and forces which everywhere pervade it, can conserve those forces at and near its farthest limits. Is it, in fact, necessarily becoming dissipated into other space? Do any of its constituent suns, like those comets which have hyperbolic or parabolic orbits, continually fly out beyond its range, and become lost to it for ever? Comparing the stars of the Milky Way to the molecules of a gas, must not a certain proportion of these stars continually escape from the attractive powers of their neighbors, as a result of collisions, or in other ways, and wandering into outer space, soon become dead and cold and lost forever to the universe? Will not the whole of the outer margins of the stellar universe be therefore unstable? always being liable to pass into regions where they would be dissipated, as we see comets dissipated before our eyes? If such results are certain, it will follow that the outer portions of the universe, at all events, and for an unknown extent inward, will be entirely unfitted to ensure that *continuity of uniform conditions* which is the first essential for the development of life.

But this is only a small portion of the problem. A still more difficult question is, how will the ether behave near the outer borders of the universe? Can gravitation maintain its influence on the confines of a finite universe in the same degree as near its center? If, as now generally believed, gravitation is really produced by pressure of some kind, which must be equal in all directions, then it is almost certain that at any considerable distance beyond the central portion of the universe, gravitation would vary in intensity in different directions. Whether this variation could possibly be detected by means of the motions of remote binary stars, or in any other way, it must be left for mathematicians and astronomers to determine.

But leaving this question of variation of the force of gravity as beyond our powers at present, we may give a little considera-

tion to those wonderful radiant forces, other than light and heat, the very existence of some of which we have only recently discovered. Such are electricity, magnetism, the Röntgen rays, the Hertzian, the Goldstein, the Becquerel rays, and some others. That electrical forces bear an important part in the development of living organisms there is little doubt, while other forms of radiation here referred to, some of which produce curious physiological effects, can hardly be supposed to have been wholly without influence in the formation of the marvelous living machine, the substance of which, in its complexity, both of structure and constituent elements, is a true microcosm — an epitome of matter and its forces. But if all these radiant forces, or several of them, have combined in the development of life, we may feel sure that they can only have done so under conditions which limit their energy to that gentle and imperceptible action which has caused them to remain so long hidden even from the most inquisitive seekers of the past century. And it is at least a possible, and I think not improbable supposition, that this imperceptibility and continuity may exist only in the more central portions of the universe, while in its outer regions less regularity may prevail, and while some of these necessary radiant forces may be wanting, others may be too abundant, or be manifested in so irregular or excessive a manner as to be antagonistic to the delicate and nicely-balanced forces which are essential to the orderly development of life.

Returning now for a moment to the consideration of our position in the stellar universe, it will assume a somewhat different aspect in view of the possibilities or probabilities just set forth.

We can hardly suppose any longer that *three* such remarkable coincidences of position and consequent physical conditions should occur in the case of the one planet, on which organic life *has* been developed, without any causal connection with that development. The three startling facts — that we *are* in the center of a cluster of suns, and that that cluster *is* situated not only precisely in the *plane* of the Galaxy, but also *centrally* in that plane, can hardly now be looked upon as chance coincidences without any significance in relation to the culminating fact that the planet so situated *has* developed humanity.

Of course the relation here pointed out *may* be a true relation

of cause and effect, and yet have arisen as the result of one in a thousand million chances occurring during almost infinite time. But, on the other hand, those thinkers may be right who, holding that the universe is a manifestation of Mind, and that the orderly development of Living Souls supplies an adequate reason why such an universe should have been called into existence, believe that we ourselves are its sole and sufficient result, and that nowhere else than near the central position in the universe which we occupy, could that result have been attained.

THE SPECTROSCOPE.

By NEWELL DUNBAR.

THOUGH we may never have thought of it before, we readily see on a little consideration that of the five senses — smell, taste, hearing, touch, and sight — to which we owe our knowledge of the world around us, we are most indebted to sight. Gathering information most easily and quickly, it gives us the greater part of our knowledge of things external; its reports too are the most reliable, and it often serves to test the credibility of the other senses. Vision it is that presents to us the beauty of the landscape, the vastness of the sea, the sun's splendor, charm of painting, wisdom or amusement from the printed page, the faces and forms of friends and dear ones. In the misty past, the strange cliff-dweller, suspended

"Like Mahomet's tomb 'twixt earth and heaven,"

chose his home by its guidance, and later the ancient Roman selected the spot to pitch his camp.

Men went on for centuries relying largely upon the unaided eye. If it could do so much what might not be expected of it if, by any seeming miracle, its natural powers were enlarged by some sort of magic spectacles! Curiously enough, just this unforeseen thing happened. Modern science — which has showered upon us so many wonders — has made three almost magical extensions to the reach of man's best sense: the microscope (invented in A. D. 1590); the telescope (1608); the spectroscope (1802). The invention of these three instruments marks epochs in the history of the human mind. The microscope added to our knowledge myriads of objects too *small* to be perceptible to the naked eye; the telescope, a vast realm too *distant* to be seen clearly, or at all. Of the spectroscope a delightful writer on scientific and other subjects, Charles Kent, says: "The spectroscope is something more than an optical instrument — it is a talisman." And the

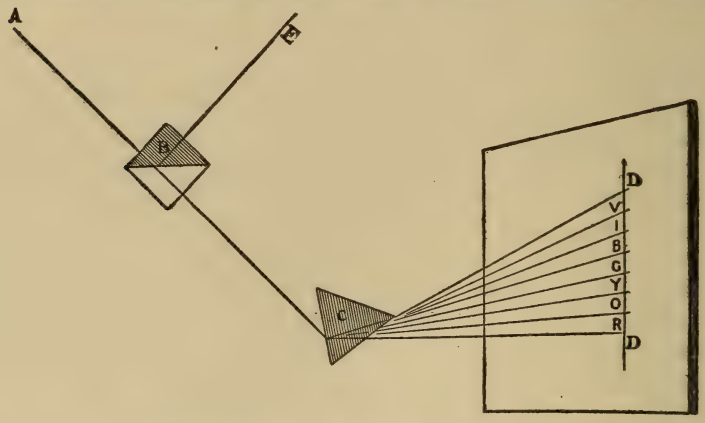
famous Alfred Russell Wallace, co-discoverer with the great Darwin of the mighty principle of natural selection, writes: "Among the numerous scientific discoveries of our [the nineteenth] century we must give a very high, perhaps even the highest, place to spectrum analysis" (which is the work the spectroscope does). "Not only because it has completely solved the problem of the true nature and cause of the various spectra produced by different kinds of light, but because it has given us a perfectly new engine of research, by which we are enabled to penetrate into the remotest depths of space, and learn something of the constitution and the motions of the constituent bodies of the stellar universe. Through its means we have acquired what are really the equivalents of new senses, which give us knowledge that before seemed absolutely and forever unattainable by man."

Perhaps we can best get a clear idea of what the spectroscope is by considering, first, the steps that led to its invention; second, a description of it; and, third, some of those of its achievements that have led scientific men — who use language with great care and accuracy — to speak of it in such glowing terms.

Even to-day, if there is one thing that on its face seems clear, it is that pure white light is just what it appears to be — namely, pure white light. But as far back as 1675 the illustrious English philosopher, Sir Isaac Newton, demonstrated the then startling fact that it contains within itself all colors. Before the assembled members of the august Royal Society he admitted through a small round hole into a darkened room a single sunbeam, in whose course inside the room he placed a glass prism. In passing through this prism the sunbeam was not only bent from a straight line, but — owing, as Newton said, to the different refrangibilities (or powers of being turned from a straight line on passing from one transparent substance into another) of light of different colors, to what we now call its different wave-lengths — was split up into seven distinct colors, which could be seen succeeding each other in a ribbon or band upon the wall: red, orange, yellow, green, blue, indigo, violet. The order of these prismatic or primary colors, as they have been called, was from the least bent rays to those which were more and more widely deflected. Each hue overlapped and shaded off imperceptibly into the next, with the result that the band or ribbon composed of them all was not divided up into distinct spaces each of a different hue, but from

end to end presented a continuous flow of occasionally gradually changing color. This variegated band is called the solar spectrum. It may often be seen on the ceiling, wall, furniture, or carpet when a ray of sunlight has passed through one of the cut-glass drops of an old-fashioned chandelier. A portion of it is produced when the sun shines upon a dewdrop; the whole, by the many raindrops of a shower in the rainbow.

Not till over a century later than the time of Newton's experiment, namely in 1802, did it occur to anybody to see what would result in it if for the small round hole were substituted a narrow slit. The celebrated English chemist, Dr. Wollaston, admitted through such a vertical slit in the shutter of the room a sunbeam, which was then duly separated into its seven constituent colors



Decomposition of Light Through Prism.

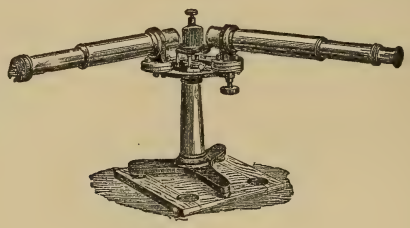
by being passed through a prism; on examining the resultant solar spectrum, greatly to his surprise Wollaston found that, from one end to the other, it was marked at irregular intervals across its width by dark lines of varying thickness. Dr. Wollaston enjoyed great reputation in his time, was secretary of the Royal Society, and acquired wealth. To-day his chief claim to remembrance is not his process of extracting platinum from its ore (on which rested his reputation during his lifetime, and his riches), but the fact of his having discovered the existence of these dark lines in the solar spectrum, though by his contemporaries the fact was deemed of very slight importance.

These dark lines in the solar spectrum were afterwards minutely studied by others. It was ascertained that, when thus formed from light admitted through a slit, the solar spectrum always showed them, and that they were invariably the same. It made no difference whether the light was derived directly from the sun, or indirectly by reflection from the moon, or from one of the planets. When, indeed, the sun being low in the east or in the west his beams had, in order to reach us, to pierce horizontally through a great thickness of the earth's atmosphere, the solar spectrum showed supplementary or additional lines; but these were clearly due to influences in the earth's air. When the light was taken at its purest, that is from the sun at meridian, the dark lines were always exactly the same in number and in manner of arrangement. The German scientist Fraunhofer — who, ignorant of Wollaston's earlier experiments, arrived afterwards by a method of his own at the same results — made out nearly six hundred of them (576, to be precise). In 1814 he published an accurate map on which each line was duly lettered and numbered, and which ever since has been of the greatest use — a standard indeed — to chemists and astronomers. Sir David Brewster counted later two thousand. On account of the thoroughness of Fraunhofer's study of the lines they were named after him, Fraunhofer's lines. So much for the steps leading to the invention of the spectroscope.

As for description, Dr. Wollaston's darkened room, prism, and slit shutter may be regarded as an imperfect and cumbrous spectroscope. So too Fraunhofer's apparatus, which was very similar; though, unlike Wollaston, Fraunhofer used a telescope for the better observing the dark lines (whereby of course they were enlarged and made plainer). But, as the importance of spectra and the cross lines began to appear and the magnitude of what might be learned from their study, the mathematical instrument makers evolved, bit by bit to meet demands, the wonderful modern spectroscope.

This, in brief, as commonly made, is a compact instrument, in its simplest form set upon a stand or table. The light to be analyzed is admitted, through an extremely narrow slit at one end, into a tube about fifteen inches long, and on issuing from the other end of this tube passes through a prism. The slit and the prism are the essential parts of the spectroscope. The spec-

trum resulting from the passage of the light through the prism is thrown upon the object-glass of a telescope, commonly about eighteen inches long, placed at an angle with the tube. The student views the spectrum through the eye-piece of this telescope. Both tube and telescope can be most delicately adjusted as to position in themselves and relatively to each other by means of screws, racks and pinions, etc. The eye-piece of the telescope is supplied with a little contrivance (called a micrometer) for determining with great accuracy the position of any line in the spectrum under observation relatively to the principal lines of Fraunhofer in the solar spectrum, the universal standard. (In many instruments the means of doing this is in the form of a second — commonly shorter — tube generally placed in the angle



The Spectroscope.

made by the other tube and the telescope.) The prism, placed at the apex of this angle, presents one of its edges to the object-glass of the tube and another to the object-glass of the telescope, the edge before the object-glass of the tube being directly parallel with the slit at its other end. In spectroscopes designed for certain particular purposes (as where high dispersion of the rays of light is desired, in photographic work, etc.), instead of a prism what is called a grating is often used. This is a collection of fine wires or scratches on glass or metal, at equal distances from and parallel with and very close to each other; it serves substantially the same purpose as a prism. Several prisms instead of one are often employed; the number has run up as high as twenty (the superb spectroscope at Kew Observatory, England, has nine). The gain from the use of a succession of prisms is that each one spreads out more and more widely the rays of light, so that the final expansion is greater, the spectrum longer, and consequently the dark lines are further separated, and so

can better be studied. Against this gain is to be set some loss in intensity to the light with each additional prism passed through. When the spectroscope is in use a dark cloth is thrown over the prism and the ends of the tube and the telescope, all extraneous light being thus excluded.*

There are various special kinds of spectroscope; as, the Chemical, the Star, the Spark, the Meteor (the particular purpose of each of which is obvious), the Direct-vision spectroscope (for use with the eye and the source of the light to be studied in a straight line), the Rain-band spectroscope (a pocket direct-vision spectroscope for studying the rain-band, which is a dark band in the solar spectrum caused by the absorption of that part of the spectrum by aqueous vapor, and giving an indication of rain), the micro-spectroscope (a microscope and a spectroscope combined, by means of which the spectra of the minutest particles can be analyzed), etc. All these in a broad sense serve substantially the same end, and in all of them the underlying principle is practically the same.

Now as to results. Of what use is this instrument? What, in detail, has it done? After Fraunhofer had, as we have seen,

* Sir Norman Lockyer, the eminent English astronomer, recently gave the following recipe for constructing at the cost of a few cents a home-made spectroscope:

"For sixpence any of us may make for ourselves an instrument. . . . From an optician we can get a small prism; get a piece of wood from twenty to ten inches long (the distance of distinct vision), one inch broad and half an inch thick. On one end glue a cork two inches high; at the other end fasten, by melting the bottom, a stump of a wax candle of such a height that the dark cone above the wick is level with the top of the cork. Then glue the prism on the cork, so that by looking sideways through the prism the colored image, or spectrum, of the flame of the candle placed at the other end of the piece of wood can be seen.

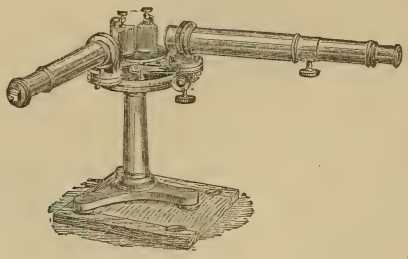
"We get a band of color, a spectrum of the candle flame, built up of an infinite number of images of the flame produced by the light rays of every color. But, so far, the spectrum is impure because the images overlap. We can get rid of this defect by replacing the candle by a needle.

"If we now allow the needle to reflect the light of the candle flame, taking care that the direct light from the candle does not fall upon the face of the prism, we then get a much purer band of colors because now we have an innumerable multitude of images of the thin needles, instead of the broad flame, close together. The needle is the equivalent of the slit of the more complicated spectroscopes used in laboratories.

"We can vary this experiment by gumming two pieces of tin-foil with two perfectly straight edges on a piece of glass so that the straight edges are parallel and very near together. In this way we have a slit; this should be fixed close to the candle and between it and the prism."

Such a spectroscope, Sir Norman Lockyer assures us, "will serve many of the purposes of demonstrating some of the marvelously fertile fields of knowledge which have recently been opened up to us."

published his map, as the spectroscope was gradually brought nearer and nearer to perfection and investigators grew more and more expert in its use, increased attention was paid to spectrum analysis. Among those who especially distinguished themselves at it may be named Dr. Ritchie, Sir John Herschel, and Fox Talbot, in England. It was found that each fresh kind of object submitted to analysis gave a spectrum of its own, distinguished by a particular color or colors, and by the number, arrangement, etc., of lines. Light can be obtained from any substance whatever if only it can be sufficiently heated. Acting on this fact investigators submitted the various chemical elements to spectroscopic test, and it was found that they produced spectra marked by *bright* instead of by dark lines. It was found too that, when these spectra were compared with the solar spectrum, some of the bright lines in the former (as, for instance, the brilliant yellow line of sodium) corresponded in position with certain black lines in the latter.



A Spectroscope With Two Prisms.

About the year 1860 the German professor, Gustav Kirchhoff — who by this time had pretty good instruments at his command — found out the meaning of the dark lines of the solar spectrum, and the significance of the correspondence between them and bright ones in the other spectra ; in so doing making a magnificent discovery, and putting into the hands of chemists and astronomers one of the most cunning tools in the whole workshop of science. He showed, practically, in the case of the spectra of various earthly substances that *dark* lines instead of the natural bright ones could be produced by causing the light emitted by the substance in question to pass through the ignited vapor of the same substance, when this vapor, while allowing the other rays

to pierce through it, absorbed the rays similar to those radiated by itself; that hence the dark lines in the solar spectrum were caused by the absorption of light at those points by incandescent vapors surrounding the sun; and that, in the case of an agreement between the lines of the spectrum of an earthly substance and lines in the solar spectrum, the same substance that produced the bright lines in one had produced the dark lines in the other, the darkness in the latter case being accounted for. This led to a study of the spectra of all the known terrestrial elements. On comparing them one by one with the solar spectrum it was found that, in many cases, there was an exact correspondence between the bright lines of one and certain black lines in the other; and thus was proved the existence in the sun's atmosphere of hydrogen, and of the vapors of the metals sodium, iron, magnesium, nickel, copper, zinc, calcium, etc. We shall be interested in noting that for certain lines in the solar spectrum no corresponding earthly element was for a long time found, and that to account for these lines there was supposed to exist in the sun an element peculiar to it, called helium. A few years ago this element was discovered in a rare mineral, and its bright spectrum exactly tallied with the unappropriated black lines in the solar spectrum!* This later actual verification of the correctness of Kirchhoff's reasoning gives it resistless force. Yet how convincing his own proof was we may see by this extract from a letter written by him in 1861: "In order to test in the most direct manner possible the truth of the frequently asserted fact of the coincidence of the sodium lines with the lines D, I obtained a tolerably bright solar spectrum, and brought a flame colored by sodium vapor in front of the slit. *I then saw the dark lines D change into bright ones"!* And again: "In order to find out the extent to which the intensity of the solar spectrum could be increased without impairing the distinctness of the sodium lines, I allowed the full sunlight to shine through the sodium flame upon the slit, and *to my astonishment I saw that the dark lines D appeared with an extraordinary degree of clearness"* (the sodium flame having, in fact, absorbed the rays having the same

* Indeed it may be said that, if the earth were raised to a temperature as high as that of the sun and were seen from a distance, its spectrum would look practically the same as the solar spectrum appears to us.

wave-lengths as those emitted by itself, while being perfectly transparent to the others)!

About the same time as Kirchhoff's grand discovery, namely in 1860, another German professor, the celebrated Bunsen, with the spectroscope discovered two metals, cæsium and rubidium; the latter in particles so infinitesimally small that by any other means they would have been imperceptible. Indeed the metal was found dissolved in the mineral water of Dürckheim, Germany, so thoroughly that less than a quarter of an ounce (two hundred grains) of it was obtained from the evaporation of forty tons of the water; yet the spectrum of the water had revealed to the relentless spectroscope an unwonted red line, and the discovery had followed! Two other new metals, making four in all, were afterwards by the same means added to the number by other investigators.

When applied to a study of the stars the spectroscope at once gave equally striking results. It was found that, while each star has a spectrum peculiar to itself, the stellar spectra as a whole are similar, indeed often very similar, to the solar spectrum. This proved the stars to be, as had previously been supposed, suns, surrounded like the sun by incandescent vapors. Much too was learned of their constitution; as, for instance, that Sirius contains hydrogen, sodium, and magnesium; Aldebaran hydrogen, iron, calcium, magnesium, etc.; and so on. Thus was brought down to us by this wizard instrument sure knowledge of worlds so distant that some of them our most powerful telescopes are able to show to us only as mere pin-points of light, and when it took the rays from which their secrets were wrested, though traveling with unimaginable speed, years to reach the confessional — in one case, that of the variable star Algol, nearly a half-century (and light traveling at the same rate of speed reaches us from the sun in just eight minutes)! Further than this, in the hands of one of its arch-masters, Sir William Huggins, the spectroscope showed (what otherwise would probably have been beyond our grasp) that certain stars — as Arcturus, and Venus at times — are moving directly toward the earth; while others — as the dog-star, Sirius — are directly receding from it. This motion in a line drawn from us to these stars was proved by a most delicate series of observations, centering in the fact of a slight change of position in the dark lines of the spectra of the stars as compared with the posi-

tion of dark lines in the spectrum of the sun or of any stationary source of light, this change being due to the fact that light-waves from an object approaching us reach us with greater rapidity than do light-waves from the same object when receding from us, as the motion of the waves is in one case accelerated and light-waves in the other retarded by the motion of the object itself. Sirius, for instance, though one of the nearest of the fixed stars, is so distant from us that its light takes twenty years in reaching the earth. Some credit must surely be given to the mystic lenses of an instrument that has enabled us to know for certain of this to the eye glorious but, it must be confessed, rather remote luminary, besides some of the metals it contains and something of the composition of its atmosphere, the fact that it has been receding straight from us for centuries at the rate of nearly thirty miles a second, and increasing its distance from the solar system every year by a thousand million miles! Indeed — probably its most stupendous feat — the spectroscope has shown that the whole solar system is moving at the rate of 150,000,000 miles a year toward a point in the constellation Hercules, the center of the sun's orbit being calculated to be Alcyone, the chief star in the Pleiades! An article in an English review as far back as 1869, after expressing a hope that *did* turn out to be prophetic that the prism might settle some of the mooted questions in regard to those gradual and imperceptible changes in the universe that go on through long periods of time (secular, as they are called), held these words, which some will think *may* contain prophecy: "It may even give the inhabitants of this earth some effective and intelligible warning that their great material system of existences is on the wane," as it "may be destined ultimately to pierce, or to remove, that hitherto impenetrable veil which seems to separate what we term organic and vital. It may one day lead us to speak even of the evolutions of thought in the terms of ordinary physics."

One of the spectroscope's most curious achievements has been to show that in some cases double stars, as they are termed (that is, two stars close together, either revolving the one round the other or without physical connection), move one toward, the other away from, us. It has demonstrated that some stars which to our most powerful telescopes seem single are really double, since their spectra show a shifting of spectrum lines, which after

a time changes to the opposite direction, it being possible from the duration of each continuous motion to calculate the time of rotation of the component stars, though one of them has never been seen by mortal eye. Thus it has been proved that the variable star Algol has an invisible companion, which partially eclipses it every sixty-nine hours, and that Procyon is likewise supplied with a dark mate. It has been shown too that the unusual motions of Sirius, which have long been known, are due, as was supposed, to the presence of a comrade, just visible in the very best telescopes.

It used to be thought, largely on the authority of Sir William Herschel, that the nebulæ — those misty clouds or patches of light that may be seen of a night at different points in the heavens, "star-dust" as they have been called — are all composed of stars, but that they are so distant from us that even the strongest telescope is unable to disentangle their component parts. This is still deemed true of many nebulæ; it is now, however, thought that on the average they are not more distant than stars. Examination of them by the spectroscope has confirmed the latter view, and shown that they are often composed merely of glowing gas, this being especially true of nebulæ in or near the Milky Way. The comets — those "prodigious blazes" and "long-streaming stars" — the same Prospero's wand, the spectroscope, has shown to us as simply huge masses of hydrogen and nitrogen gas, rushing through space at frightful speed, and in a state of glowing incandescence.

In practical life the spectroscope has proved useful in various ways; for instance, in the Bessemer manufacturng process by showing the precise moment for transforming iron into steel by blowing air through it when it has become thoroughly molten in its cupola furnaces. Many more ways might be suggested. It might be found valuable in the detection of adulterations, as in wine, or even in the discovery of crime; by the micro-spectroscope, for example, from the unmistakable dark bands in its spectrum can be detected the presence of the thousandth part of a grain of blood — enough, conceivably, to hang a murderer! The presence of poisons in bodies might be similarly ferreted out. It may here be noted that in England Dr. Bence Jones by means of the spectroscope discovered in a living body the presence of certain metallic atoms that had been introduced into it only a few min-

utes before. As additional evidence of the almost miraculous delicacy of the spectroscope's workings it may be said that it plainly detects the tell-tale yellow line in the spectrum of so small a bit of sodium as the 195-millionth part of a grain, an amount infinitesimal almost beyond conception! Amazing as we are now likely to concede the revelations of the spectroscope, which is practically a thing but of yesterday, to have been, they are undoubtedly but just beginning. How many more of them, and what, the future has in store for us — here on earth, there in the heavens — only the future can tell.

LIFE IN THE DEEP SEA.

From the QUARTERLY REVIEW, July, 1902.

THE first recorded attempt to sound the depths of the ocean was made early in the year 1521, in the South Pacific, by Ferdinand Magellan. He had traversed the dangerous Straits destined to bear his name during the previous November, and emerged on the 28th of that month into the open ocean. For three months he sailed across the Pacific, and in the middle of March, 1521, came to anchor off the islands now known as the Philippines. Here Magellan was killed in a conflict with the natives. The records of his wonderful feat were brought to Spain during the following year by one of his ships, the *Victoria;* and amidst the profound sensation caused by the news of this voyage, which has been called "the greatest event in the most remarkable period of the world's history," it is probable that his modest attempt to sound the ocean failed to attract the attention it deserved. Magellan's sounding-lines were at most some two hundred fathoms in length, and he failed to touch bottom; from which he "somewhat naïvely concluded that he had reached the deepest part of the ocean."

It was more than two hundred years later that the first serious study of the bed of the sea was undertaken by the French geographer, Philippe Buache, who first introduced the use of isobathic curves in a map which he published in 1737. His view, that the depths of the ocean are simply prolongations of the conditions existing in the neighboring sea-coasts, though too wide in its generalization, has been shown to be true as regards the sea-bottom in the immediate vicinity of continental coasts and islands; and undoubtedly it helped to attract attention to the problem of what is taking place at the bottom of the sea.

Actual experiment, however, advanced but slowly. So early as the fifteenth century, an ingenious cardinal, one Nicolaus Cusanus (1401-64), had devised an apparatus consisting of two

bodies, one heavier and one lighter than water, which were so connected that when the heavier touched the bottom the lighter was released. By calculating the time which the latter took in ascending, attempts were made to arrive at the depths of the sea. A century later Puehler made similar experiments; and after another interval of a hundred years, in 1667, we find the Englishman, Robert Hooke, continuing on the same lines various bathymetric observations; but the results thus obtained were fallacious, and the experiments added little or nothing to our knowledge of the nature of the bottom of the ocean. In the eighteenth century Count Marsigli attacked many of the problems of the deep sea. He collected and sifted information which he derived from the coral-fishers; he investigated the deposits brought up from below, and was one of the earliest to test the temperature of the sea at different depths. In 1749 Captain Ellis found that a thermometer, lowered on separate occasions to depths of 650 fathoms and 891 fathoms respectively, recorded, on reaching the surface, the same temperature, namely, 53°. His thermometer was lowered in a bucket ingeniously devised so as to open as it descended and close as it was drawn up. The mechanism of this instrument was invented by the Rev. Stephen Hales, D.D., of Corpus Christi College, Cambridge, the friend of Pope, and perpetual curate at Teddington Church. Dr. Hales was a man of many inventions, and, amongst others, he is said to have suggested the use of the inverted cup placed in the center of a fruit-pie in which the juice accumulates as the pie cools. His device of the closed bucket with two connected valves was the forerunner of the numerous contrivances which have since been used for bringing up sea-water from great depths.

These were amongst the first efforts made to obtain a knowledge of deep-sea temperatures. About the same time experiments were being made by Bouguer and others on the transparency of sea-water. It was soon recognized that this factor varies in different seas; and an early estimate of the depth of average sea-water sufficient to cut off all light placed it at 656 feet. The color of the sea and its salinity were also receiving attention, notably at the hands of the distinguished chemist, Robert Boyle, and of the Italian, Marsigli, mentioned above. To the latter, and to Donati, a fellow-countryman, is due the

honor of first using the dredge for purposes of scientific inquiry. They employed the ordinary oyster-dredge of the local fishermen to obtain animals from the bottom.

The invention of the self-registering thermometer by Cavendish, in 1757, provided another instrument essential to the investigation of the condition of things at great depths; and it was used in Lord Mulgrave's expedition to the Arctic sea in 1773. On this voyage, attempts at deep-sea soundings were made, and a depth of 683 fathoms was registered. During Sir James Ross' Antarctic expedition (1839–43) the temperature of the water was constantly observed to depths of 2,000 fathoms. His uncle, Sir John Ross, had twenty years previously, on his voyage to Baffin's Bay, made some classical soundings. One, two miles from the coast, reached a depth of 2,700 feet, and brought up a collection of gravel and two living crustaceans; another, 3,900 feet in depth, yielded pebbles, clay, some worms, crustacea, and corallines. Two other dredgings, one at 6,000 feet, the other at 6,300 feet, also brought up living creatures; and thus, though the results were not at first accepted, the existence of animal life at great depths was demonstrated.

With Sir James Ross' expedition we may be said to have reached modern times: his most distinguished companion, Sir Joseph Hooker, is still living. It is impossible to do more than briefly refer to the numerous expeditions which have taken part in deep-sea exploration during our own times. The United States of America sent out, about the time of Ross' Antarctic voyage, an expedition under Captain Wilkes, with Dana on board as naturalist. Professor Edward Forbes, who "did more than any of his contemporaries to advance marine zoology," joined the surveying ship *Beacon* in 1840, and made more than one hundred dredgings in the Ægean Sea. Lovén was working in the Scandinavian waters. Mr. H. Goodsir sailed on the Erebus with Sir John Franklin's ill-fated polar expedition; and such notes of his as were recovered bear evidence of the value of the work he did. The Norwegians, Michael Sars and his son, G. O. Sars, had by the year 1864 increased their list of species living at a depth of between 200 and 300 fathoms, from nineteen to ninety-two. Much good work was done by the United States navy and by surveying ships under the auspices of Bache, Bailey, Maury, and de Pourtalès. The Austrian

frigate, *Novaria,* with a full scientific staff, circumnavigated the world in 1857–59. In 1868 the Admiralty placed the surveying ship, *Lightning,* at the disposal of Professor Wyville Thomson and Dr. W. B. Carpenter for a six weeks' dredging trip in the North Atlantic; and in the following year the *Porcupine,* by permission of the Admiralty, made three trips under the guidance of Dr. W. B. Carpenter and Mr. Gwyn Jeffreys.

Towards the end of 1872 H.M.S. *Challenger* left England, to spend the following three years and a half in traversing all the waters of the globe. This was the most completely equipped expedition which has left any land for the investigation of the sea, and its results were correspondingly rich. They have been worked out by naturalists of all nations, and form the most complete record of the fauna and flora, and of the physical and chemical conditions of the deep which has yet been published. It is from Sir John Murray's summary of the results of the voyage that many of these facts are taken. Since the return of the *Challenger* there have been many expeditions from various lands, but none so complete in its conception or its execution as the British expedition of 1872–75. The U.S.S. *Blake,* under the direction of A. Agassiz, has explored the Caribbean Sea; and the *Albatross,* of the same navy, has sounded the western Atlantic. Numerous observations made by the German ships, *Gazelle* and *Drache,* and by the "Plankton" expedition; by the Norwegian North Atlantic expedition; the Italian ship, *Washington;* the French ships, *Travailleur* and *Talisman;* the Prince of Monaco's yachts, *Hirondelle* and *Princesse Alice,* under his own direction; the Austrian "Pola" expedition; the Russian investigations in the Black Sea, and lastly, by the ships of our own navy, have, during the last five-and-twenty years, enormously increased our knowledge of the seas and of all that in them is. This knowledge is still being added to. At the present time the collections of the German ship, *Valdivia,* are being worked out, and are impatiently awaited by zoologists and geographers of every country. The *Discovery* and the *Gauss* although primarily fitted for ice-work, can hardly fail to add much to what is known of the sea-bottom; and amongst men of science there is no abatement of interest and curiosity as to that *terra incognita.*

Before we attempt to describe the conditions which prevail

at great depths of the ocean, a few words should be said as to the part played by cable-laying in the investigation of the subaqueous crust of the earth. This part, though undoubtedly important, is sometimes exaggerated; and we have seen how large an array of facts has been accumulated by expeditions made mainly in the interest of pure science. The laying of the Atlantic cable was preceded, in 1856, by a careful survey of a submerged plateau, extending from the British isles to Newfoundland, by Lieutenant Berryman of the *Arctic.* He brought back samples of the bottom from thirty-four stations between Valentia and St. John's. In the following year Captain Pullen, of H.M.S. *Cyclops,* surveyed a parallel line slightly to the north. His specimens were examined by Huxley, and from them he derived the *Bathybius,* a primeval slime which was thought to occur widely spread over the sea-bottom. The interest in this "Urschleim" has, however, become merely historic, since John Y. Buchanan, of the *Challenger,* showed that it is only a gelatinous form of sulphate of lime thrown down from the sea-water by the alcohol used in preserving the organisms found in the deep-sea deposits.

The important generalizations of Dr. Wallich, who was on board H.M.S. *Bulldog,* which, in 1860, again traversed the Atlantic to survey a route for the cable, largely helped to elucidate the problems of the deep. He noticed that no *algæ* live at a depth greater than 200 fathoms; he collected animals from great depths, and showed that they utilize in many ways organisms which fall down from the surface of the water; he noted that the conditions are such that, whilst dead animals sink from the surface to the bottom, they do not rise from the bottom to the surface; and he brought evidence forward in support of the view that the deep-sea fauna is directly derived from shallow-water forms. In the same year in which Wallich traversed the Atlantic, the telegraph cable between Sardinia and Bona, on the African coast, snapped. Under the superintendence of Fleeming Jenkin, some forty miles of the cable, part of it from a depth of 1200 fathoms, was recovered. Numerous animals, sponges, corals, polyzoa, molluscs, and worms were brought to the surface, adhering to the cable. These were examined and reported upon by Professor Allman, and subsequently by Professor A. Milne Edwards; and, as the former reports, we "must therefore regard

this observation of Mr. Fleeming Jenkin as having afforded the first absolute proof of the existence of highly organized animals living at a depth of upwards of 1,000 fathoms." The investigation of the animals thus brought to the surface revealed another fact of great interest, namely that some of the specimens were identical with forms hitherto known only as fossils. It was thus demonstrated that species hitherto regarded as extinct are still living at great depths of the ocean.

During the first half of the last century an exaggerated idea of the depth of the sea prevailed, due in a large measure to the defective sounding apparatus of the time. Thus Captain Durham, in 1852, recorded a depth of 7,730 fathoms in the South Atlantic, and Lieutenant Parker mentions one of 8,212 fathoms — depths which the *Challenger* and the *Gazelle* corrected to 2,412 and 2,905 fathoms respectively. The deepest parts of the sea, as revealed by recent research, do not lie, as many have thought, in or near the centers of the great oceans, but in the neighborhood of, or at no great distance from, the mainland, or in the vicinity of volcanic islands. One of the deepest "pockets" yet found is probably that sounded by the American expedition on board the *Tuscarora* (1873-75) east of Japan, when bottom was only reached at a depth of 4,612 fathoms. More recently, soundings of 5,035 fathoms have been recorded in the Pacific, in the neighborhood of the Friendly Islands, and south of these again, one of 5,113 fathoms; but the deepest of all lies north of the Carolines, and attains a depth of 5,287 fathoms. It thus appears that there are "pockets" or pits in the sea whose depth below the surface of the water is about equal to the height of the highest mountains taken from the sea-level. Both are insignificant in comparison with the mass of the globe; and it is sometimes said that, were the seas gathered up, and the earth shrunk to the size of an orange, the mountain-ranges and abysmal depths would not be more striking than are the small elevations and intervening depressions on the skin of an orange.

But it is not with these exceptional abysses that we have to do; they are as rare and as widely scattered as great mountain-ranges on land. It is with the deep sea, as opposed to shoal water and the surface layers, that this article is concerned; but the depth at which the sea becomes "deep" is to some extent a

matter of opinion. Numerous attempts, headed by that of Edward Forbes, have been made to divide the sea into zones or strata; and, just as the geological strata are characterized by peculiar species, so, in the main, the various deep-sea zones have their peculiar fauna. These zones, however, are not universally recognized; and their limits, like those of the zoogeographical regions on land, whilst serving for some groups of animals, break down altogether as regards others. There are, however, two fairly definite regions in the sea; and the limit between them is the very one for our purpose. This limit separates the surface waters, which are permeable by the light of the sun, and in which, owing to this life-giving light, *algæ* and vegetable organisms can live, from the deeper waters which the sun's rays cannot reach, and in which no plant can live. The regions pass imperceptibly into one another; there is no sudden transition. The conditions of life gradually change, and the precise level at which vegetable life becomes impossible varies with differing conditions. With strong sunlight and a smooth sea, the rays penetrate further than if the light be weak and the waters troubled.

Speaking generally, we may place the dividing-line between the surface layer and the deep sea at 300 fathoms. Below this no light or heat from the sun penetrates; and it is the absence of these factors that gives rise to most of the peculiarities of the deep sea. It is a commonplace which every school-boy now knows, that all animal life is ultimately dependent on the food-stuffs stored up by green plants; and that the power which such plants possess of fixing the carbonic acid of the surrounding medium, and building it up into more complex food-stuffs, depends upon the presence of their green coloring matter (chlorophyll), and is exercised only in the presence of sunlight. But, as we have pointed out, "the sun's perpendicular rays" do not "illumine the depths of the sea"; they hardly penetrate 300 fathoms. This absence of sunlight below a certain limit, and the consequent failure of vegetable life, gave rise at one time to the belief that the abysses of the ocean were uninhabited and uninhabitable; but, as we have already seen, this view has long been given up.

The inhabitants of the deep sea cannot, any more than other creatures, be self-supporting. They prey on one another, it is

true; but this must have a limit, or very soon there would be nothing left to prey upon. Like the inhabitants of great cities, the denizens of the deep must have an outside food-supply, and this they must ultimately derive from the surface layer.

The careful investigation of life in the sea has shown that not only the surface layer, but all the intermediate zones teem with life. Nowhere is there a layer of water in which animals are not found. But, as we have seen, the *algæ* upon which the life of marine animals ultimately depends, live only in the upper waters; below 100 fathoms they begin to be rare, and below 200 fathoms they are absent. Thus it is evident that those animals which live in the surface layers have, like an agricultural population, their food-supply at hand, whilst those that live in the depths must, like dwellers in towns, obtain it from afar. Many of the inhabitants of what may be termed the middle regions are active swimmers, and these undoubtedly from time to time visit the more densely peopled upper strata. They also visit the depths and afford an indefinite food-supply to the deep-sea dwellers.

But probably by far the larger part of the food consumed by abysmal creatures consists of the dead bodies of animals which sink down like manna from above. The surface layers of the ocean teem with animal and vegetable life. Every yachtsman must at times have noticed that the sea is thick as a *purée* with jelly-fish, or with that little transparent, torpedo-shaped creature, the *Sagitta*. What he will not have noticed, unless he be a microscopist, is that at almost all times the surface is crowded with minute organisms, foraminifera, radiolaria, diatoms. These exist in quite incalculable numbers, and reproduce their kind with astounding rapidity. They are always dying, and their bodies sink downwards like a gentle rain. In such numbers do they fall, that large areas of the ocean bed are covered with a thick deposit of their shells. In the shallower waters the foraminifera, with their calcareous shells, prevail, but over the deeper abysses of the ocean they take so long in falling that the calcareous shells are dissolved in the water, which contains a considerable proportion of carbonic acid gas, and their place is taken by the siliceous skeletons of the radiolarians and diatoms. Thus there is a ceaseless falling of organisms from above, and it must be from these that the dwellers of the deep ultimately

obtain their food. As Mr. Kipling, in his "Seven Seas," says of the deep-sea cables,

> "The wrecks dissolve above us; their dust drops down from afar —
> Down to the dark, to the utter dark, where the blind white sea-snakes are."

In trying to realize the state of things at the bottom of the deep sea, it is of importance to recognize that there is a wonderful uniformity of physical conditions *là-bas*. Climate plays no part in the life of the depths; storms do not ruffle their inhabitants; these recognize no alternation of day or night; seasons are unknown to them; they experience no change of temperature. Although the abysmal depths of the polar regions might be expected to be far colder than those of the tropics, the difference only amounts to a degree or so — a difference which would not be perceptible to us without instruments of precision. The following data show how uniform temperature is at the bottom of the sea.

In June, 1883, Nordenskiöld found on the eastern side of Greenland the following temperatures at the surface 2.2° C.; at 100 metres 5.7° C.; at 450 m. 5.1° C. In the middle of December, 1898, the German deep-sea expedition, while in the pack-ice of the Antarctic, recorded the following temperatures: at the surface —1° C.; at 100 m. —1.1° C.; at 400 m. 1.6° C.; at 1000-1500 m. 1.6° C.; at 4700 m.—0.5° C. These may be compared with some records made in the Sargasso Sea by the Plankton expedition in the month of August, when the surface registered a temperature of 24° C.; 195 m. one of 18.8° C.; 390 m. one of 14.9° C.; and 2060 m. one of 3.8 C. It is thus clear that the temperature at the bottom of the deep sea varies but a few degrees from the freezing-point; and, whether in the tropics or around the poles, this temperature does not undergo anything like the variations to which the surface of the earth is subjected.

There are, however, some exceptions to this statement. The Mediterranean, peculiar in many respects, is also peculiar as to its bottom temperature. In August, 1881, the temperature, as taken by the *Washington,* was at the surface 26° C.; at 100 m. 14.5° C.; at 500 m. 14.1° C.; and from 2500 m. to 3550 m. 13.3° C. These observations agree, within one fifth of a degree, with those recorded later by Chun in the same waters. There

are also certain areas near the Sulu Islands where, with a surface temperature of 28° C., the deep sea, from 730 m. to 4660 m., shows a constant temperature of 10.3° C.; and again, on the westerly side of Sumatra, the water, from 900 m. downwards, shows a constant temperature of 5.9° C.; whilst, in the not far distant Indian Ocean, it sinks at 1300 m. to 4° C. and at 1700 m. to 3° C. In spite of these exceptions, we may roughly say that all deep-sea animals live at an even temperature, which differs by but a few degrees from the freezing-point. Indeed, the heating effect of the sun's rays is said not to penetrate, as a rule, further than 90–100 fathoms, though in the neighborhood of the Sargasso Sea it undoubtedly affects somewhat deeper layers. In the Mediterranean the heat rays probably do not penetrate more than 50 fathoms. Below these limits all seasonable variations cease. Summer and autumn, spring and winter, are unknown to the dwellers of the deep; and the burning sun of the tropical noonday, which heats the surface water to such a degree that the change of temperature from the lower waters to the upper proves fatal to many delicate animals when brought up from the depths, has no effect on the great mass of water below the 100-fathom line.

Again, in the depths the waters are still. A great calm reigns. The storms which churn the upper waters into tumultuous fury have but a superficial effect, and are unfelt at the depth of a few fathoms. Even the great ocean-currents, such as the Gulf-stream, are but surface-currents, and their influence is probably not perceptible below 200 fathoms. There are places, as the wear and tear of telegraphic cables show, where deep-sea currents have much force; but these are not common. We also know that there must be a very slow current flowing from the poles towards the equator. This replaces the heated surface-waters of the tropics, which are partly evaporated and partly driven by the trade-winds towards the poles. Were there no such current, the waters round the equator, in spite of the low conductivity of salt water, would, in the course of ages, be heated through. But this current is almost imperceptible; on the whole, no shocks or storms disturb the peace of the oceanic abyss.

An interesting result of this is that many animals, which in shallower waters are subject to the strain and stress of tidal

action or of a constant stream, and whose outline is modified by these conditions, are represented in the depths by perfectly symmetrical forms. For instance, the monaxonid sponges from the deep sea have a symmetry as perfect as a lily's, whilst their allies from the shallower seas, subject as they are to varying tides and currents, are of every variety of shape, and their only common feature is that none of them are symmetrical. This radial symmetry is especially marked in the case of sessile animals, those whose "strength is to sit still," attached by their base to some rock or stone, or rooted by a stalk into the mud. Such animals cannot move from place to place, and, like an oyster, are dependent for their food on such minute organisms as are swept towards them in the currents set by the action of their cilia. A curious and entirely contrary effect is produced by this stillness on certain animals which, without being fixed, are, to say the least, singularly inert. The sea-cucumbers or holothurians, which can be seen lying still as sausages in any shallow sub-tropical waters, are nevertheless rolled over from time to time, and present now one, now another, surface to the bottom. These have retained the five-rayed symmetry which is so eminently characteristic of the group Echinoderma, to which they belong. But the holothurians in the deep sea, where nothing rolls them about, continue throughout life to present the same surface to the bottom; and these have developed a secondary bilateral symmetry, so that, like a worm or a lobster, they have definite upper and lower surfaces. These bilateral holothurians first became known by the dredgings of the *Challenger*, and formed one of the most important additions to our knowledge of marine zoology for which we are indebted to that expedition.

At the bottom of the sea there is no sound —

> "There is no sound, no echo of sound, in the deserts of the deep,
> Or the great grey level plains of ooze where the shell-burred cables creep."

The world down there is cold and still and noiseless. Nevertheless many of the animals of the depths have organs to which by analogy an auditory function has been assigned. But it must not be forgotten that even in the highest land-vertebrates the ear has two functions. It is at once the organ of hearing and

of balancing. Part of the internal ear is occupied with orientating the body. By means of it we can tell whether we are keeping upright, going up-hill or descending, turning to the right or to the left; and it is probably this function which is the chief business of the so-called ears of marine animals. Professor Huxley once said that, unless one became a crayfish, one could never be sure what the mental processes of a crayfish were. This is doubtless true; but experiment has shown, both in crayfishes and cuttlefishes, that if the auditory organ be interfered with or injured, the animal loses its sense of direction and staggers hither and thither like a drunken man. It is obvious that animals which move about at the bottom require such balancing organs quite as much as those which skim the surface; and it is in no wise remarkable that such organs should be found in those dwellers in the deep which move from place to place.

If we could descend to the depths and look about us, we should find the bottom of the sea near the land carpeted with deposits washed down from the shore and carried out to sea by rivers, and dotted over with the remains of animals and plants which inhabit shoal waters. This deposit, derived from the land, extends to a greater or less distance around our coast-line. In places this distance is very considerable. The Congo is said to carry its characteristic mud six hundred miles out to sea, and the Ganges and the Indus to carry theirs a thousand miles; but sooner or later we should pass beyond the region of coast mud and river deposit, the seaward edge of which is the "mud-line" of Sir John Murray.

When we get beyond the mud-line, say a hundred miles from the Irish or American coast, we should find that the character of the sea-bottom has completely changed. Here we should be on Rudyard Kipling's "great grey level plains of ooze." All around us would stretch a vast dreary level of grayish-white mud, due to the tireless fall of the minute globigerina shells mentioned above. This rain of foraminifera is ceaseless, and serves to cover rock and stone alike. It is probably due to this chalky deposit that so many members of the "Benthos" — a term used by Haeckel to denote those marine animals which do not swim about or float, but which live on the bottom of the ocean either fixed or creeping about — are stalked. Many of them, whose shoal-water allies are without a pedicel, are pro-

vided with stalks; and those whose shallow-water congeners are stalked are, in the depths, provided with still longer stalks. Numerous sponges — the alcyonarian *Umbellula,* the stalked ascidians, and, above all, the stalked crinoids — exemplify this point.

Flat as the Sahara, and with the same monotony of surface, these great plains stretch across the Atlantic, dotted here and there with a yet uncovered stone or rock dropped by a passing iceberg. In the deeper regions of the ocean — where, as we have already seen, occasional pits and depressions occur, and great ridges arise to vex the souls of the cable-layers — the globigerina ooze is replaced by the less soluble siliceous shells of the radiolarians and diatoms. The former are largely found in pits in the Pacific, the latter in the Southern Seas. But there is a third deposit which occurs in the deeper parts of the ocean — the red clay. This is often partly composed of the empty siliceous shells just mentioned; but over considerable areas of the Pacific the number of these shells is very small, and here it would seem that the red clay is largely composed of the "horny fragments of dead surface-living animals, of volcanic and meteoric dust, and of small pieces of water-logged pumice-stone." On whichever deposit we found ourselves, could we but see the prospect, we should be struck with the monotony of a scene as different as can well be imagined from the varigated beauty of a rock-pool or a coral island lagoon.

There is, however, an abundance of animal life. The dredge reveals a surprising variety and wealth of form. Sir John Murray records "at station 146 in the Southern Ocean, at a depth of 1,375 fathoms, that 200 specimens captured belonged to 59 genera and 78 species." He further states that this was "probably the most successful haul, as regards number, variety, novelty, size, and beauty of the specimens," up to the date of the dredging; but even this was surpassed by the captures from the depths at station 147. The Southern Ocean is particularly well populated. The same writer says: "The deep-sea fauna of the Antarctic has been shown by the *Challenger* to be exceptionally rich, a much larger number of species having been obtained than in any other region visited by the expedition; and the *Valdivia's* dredgings, in 1898, confirm this." There seems to be no record of such a wealth of species in depths of less than 50 fathoms,

and we are justified in the belief that the great depths are extremely rich in species.

The peculiar conditions under which the Benthos live has had a marked influence on their structure. Representatives of nearly all the great divisions of the animal kingdom which occur in the sea are found in the depths. Protozoa, sponges, cœlenterata, round-worms, annelids, crustacea, polyzoa, brachiopoda, molluscs, echinoderms, ascidians, fishes, crowd the sea-bottom. The *Valdivia* has brought home even deep-sea ctenophores and sagittas, forms hitherto associated only with life at the surface. The same expedition also secured adult examples of the wonderful free-swimming holothurian, *Pelagothuria ludwigi*, which so curiously mimics a jelly-fish. It was taken in a closing-net at 400–500 fathoms near the Seychelles. Most of these animals bear their origin stamped on their structure, so that a zoologist can readily pick out from a miscellaneous collection of forms those which have a deep-sea home. We have already referred to a certain "stalkiness," which lifts the fixed animals above the slowly deepening ooze. Possibly the long-knobbed tentacles of the deep-sea jelly-fish, *Pectis,* on the tips of which it is thought the creature moves about, may be connected with the same cause. The great calm of the depths and its effect upon the symmetry of the body have also been mentioned; but greater in its effect on the bodies of the dwellers in the ocean abysses is the absence of sunlight.

No external rays reach the bottom of the sea, and what light there is must be supplied by the phosphorescent organs of the animals themselves, and must be faint and intermittent. A large percentage of animals taken from the deep sea show phosphorescence when brought on deck; and it may be that this emission of light is much greater at a low temperature, and under a pressure of one or two tons on the square inch, than it is under the ordinary atmospheric conditions of the surface. The simplest form which these phosphorescent organs take is that of certain skin-glands which secrete a luminous slime. Such a slime is cast off, according to Filhol, by many of the annelids; and a similar light-giving fluid is exuded from certain glands at the base of the antenna and elsewhere in some of the deep-sea shrimps. But the most highly developed of the organs which produce light are the curious eye-like lan-

terns which form one or more rows along the bodies of certain fishes, notably of members of the Stomiadæ, a family allied to the salmons. From head to tail the miniature bull's-eyes extend, like so many port-holes lit up, with sometimes one or two larger organs in front of the eyes, like the port and starboard lanterns of a ship, so that when one of these fishes swims swiftly across the dim scene it must, to quote Kipling again, recall a liner going past "like a grand hotel." Sometimes the phosphorescent organ is at the tip of a barbel or tentacle, and it is interesting to note that the angler-fish of the deep sea has replaced its white lure, conspicuous in shallow water, but invisible in the dark, by a luminous process, the investigation of which leads many a creature into the enormous toothed mouth of the fish.

A peculiar organ exists in the body of certain radiolarians found only in the deep seas and known by the name "phæodaria." It has been suggested that this structure gives forth light; and, if this be the case, the floor of the ocean is strewn with minute glow-lamps, which perhaps give forth as much light as the surface of the sea on a calm summer's night. There is, however much indirect evidence that, except for these intermittent sources, the abysses of the ocean are sunk in an impenetrable gloom.

When physical conditions change, living organisms strive to adapt themselves to the changed conditions. Hence, when the inhabitants of the shallower waters made their way into the darker deeps, many of them, in the course of generations, increased the size of their eyes until they were out of all proportion to their other sense-organs. Others gave up the contest on these lines and set about replacing their visual organs by long tactile tentacles or feelers, which are extraordinarily sensitive to external impressions. Like the blind, they endeavor to compensate for loss of sight by increased tactile perception; and in these forms the eyes are either dwindling or have quite disappeared. An instance in point is supplied by the crustacea, many of whom have not only lost their eyes but have also lost the stalk which bore them; but amongst the crustacea some genera, such as *Bathynomus,* have enormous eyes with as many as four thousand facets. It is noticeable that this creature has its eyes directed downwards towards the ground and not up-

wards, as is the case with its nearest allies. On the whole the crustacea lose their eyes more readily, and at a less depth, than fishes. Many of the latter, e.g. *Ipnops,* are blind, and in others the eyes seem to be disappearing. Thus, amongst the deep-sea cod, *Macrurus,* those which frequent the waters down to about 1000 fathoms have unusually large eyes, whilst those which go down to the deeper abysses have very small ones. Many of the animals which have retained their eyes carry them at the end of processes. Chun, in his brilliant account of the voyage of the *Valdivia,* has figured a series of fishes whose eyes stand out from the head like a pair of binoculars; and similar "telescope" eyes, as he calls them, occur on some of the eight-armed cuttle-fish. The larva of one of the fishes has eyes at the end of two stalks each of which measures quite one fourth of the total length of the body.

The color of the deep-sea creatures also indicates the darkness of their habitat. Like cave-dwelling animals, or the lilac forced in Parisian cellars, many of them are blanched and pale; but this is by no means always the case. There is, in fact, no characteristic hue for the deep-sea fauna. Many of the fishes are black, and many show the most lovely metallic sheen. Burnished silver and black give a somewhat funereal, but very tasteful appearance to many a deep-sea fish. Others are ornamented with patches of shining copper, which, with their blue eyes, form an agreeable variety in their otherwise somber appearance. Many of the fishes, however, present a gayer clothing. Some are violet, others pale rose or bright red. Others have a white almost translucent skin through which the blood can be seen and its course traced even in its finer threads. Purples and greens abound amongst the holothurians; other echinoderms are white, yellow, pink, or red. Red is perhaps the predominant color of the crustacea, though it has been suggested that this color is produced during the long passage to the surface, and that some of the bright reds which we see at the surface are unknown in the depths. Violet and orange, green and red, are the colors of the jelly-fishes and the corals.

It thus appears that there is a great variety and a great brilliancy amongst many of the bottom fauna. With the exception of blue, all colors are well represented; but the consideration of one or two facts seems to show that color plays little

part in their lives. Apart from the fact that to our eyes, at any rate, these gorgeous hues would be invisible in the depths, it is difficult to imagine that each of these gayly-colored creatures can live amongst surroundings of its own hue. Again, it is characteristic that the color is uniform. There is a marked absence of those stripes, bands, spots, or shading which play so large a part in the protective coloration of animals exposed to light. Although there is no protective coloration amongst the animals of the deep sea, the luminous organs, which make, for instance, some of the cuttle-fishes as beautiful and as conspicuous as a firework, may, in some cases, act as warning signals. Having once established a reputation for nastiness, the more conspicuous an animal can make itself the less likely is it to be interfered with. One peculiarity connected with pigment, as yet inexplicable, is the fact that, in deep-sea animals, many of the cavities of the body are lined with a dark or, more usually, a black epithelium. The mouth, pharynx, and respiratory channels, and even the visceral cavity, of *Bathysaurus* and *Ipnops,* and indeed of all really deep-sea fishes, are black. It can be of no use to any animal to be black inside; and the only explanation hitherto given is that the deposit of pigment is the expression of some modification in the excretory processes of the abysmal fishes.

It was mentioned above that the absence of eyes is to some extent compensated by the great extension of feelers and antennæ. Many of the jelly-fishes have long free tentacles radiating in all directions; the rays of the ophiuroids are prolonged; the arms of the cuttle-fish are capable of enormous extension. The antennæ of the crustacea stretch out through the water and, in *Aristoeopsis,* cover a radius of about five times the body-length. In *Nematocarcinus* the walking-legs are elongated to almost the same extent; and this crustacean steps over the sea-bottom with all the delicacy of Agag. The curious arachnid-like pycnogonids have similarly elongated legs, and move about, like the "harvestmen" or the "daddy-long-legs," with each foot stretched far from the body, acting as a kind of outpost. The fishes, too, show extraordinary outgrowths of this kind. The snout may be elongated till the jaws have the proportions of a pair of scissor-blades, each armed with rows of terrible teeth; or long barbels, growing out from around the mouth, sway to

and fro in the surrounding water. In other cases the fins are drawn out into long streamers. All these eccentricities give the deep-sea fishes a bizarre appearance; their purpose is plainly to act as sensory outposts, warning their possessor of the presence of enemies or of the vicinity of food.

All deep-sea animals are of necessity carnivorous, and probably many of them suffer from an abiding hunger. Many of the fishes have enormous jaws, the angle of the mouth being situated at least one third of the body-length from the anterior end. The gape is prodigious, and as the edge of the mouth is armed with recurved teeth, food once entering has little chance of escape. So large is the mouth that these creatures can swallow other fish bulkier than themselves; and certain eels have been brought to the surface which have performed this feat, the prey hanging from beneath them in a sac formed of the distended stomach and body-wall. It has been said of the desert fauna that "perhaps there never was a life so nurtured in violence, so tutored in attack and defense as this. The warfare is continuous from the birth to the death." The same words apply equally to the depths of the ocean. There, perhaps, more than anywhere else, is true the Frenchman's description of life as the conjugation of the verb "I eat," with its terrible correlative "I am eaten."

Connected with the alimentary tract, though in some fishes shut off from it, is the air-bladder, an organ which contains air secreted from the blood, and which, amongst other functions, serves to keep the fish the right side up. The air can be reabsorbed, and is no doubt, to some extent, controlled by muscular effort; but there are times when this air-bladder is a source of danger to deep-sea fishes. When they leave the depths for shallower water, where the pressure is diminished, the air-bladder begins to expand; and, should this expansion pass beyond the control of the animal, the air-bladder will act as a balloon, and the fish will continue to rise with a rate of ascension which increases as the pressure lessens. Eventually the fish reaches the surface in a state of terrible distortion, with half its interior hanging out of its mouth. Many such victims of levitation have been picked up at sea, and from them we learnt something about deep-sea fishes before the self-closing dredge came into use.

One peculiarity of the abysmal fauna, which, to some extent, is a protection against the cavernous jaws mentioned above, is a certain "spininess" which has developed even amongst genera that are elsewhere smooth. Such specific names as *spinosus, spinifer, quadrispinosum,* are very common in lists of deep-sea animals, and testify to the wide prevalence of this form of defense. A similar spiny character is, however, found in many polar species, even in those of comparatively shallow water; and it may be that this feature is a product of low temperature and not of low level. The same applies to the large size which certain animals attain in the depths. For instance, in the Arctic and Antarctic Seas the isopodous crustacea, which upon our coasts scarcely surpass an inch in length, grow to nine or ten inches, with bodies as big as moderate-sized lobsters. The gigantic hydroid polyps, e.g. *Monocaulus imperator* of the Pacific and Indian Oceans, illustrate the same tendency; and so do the enormous single spicules, several feet long and as thick as one's little finger, of the sponge *Monorhaphis.* Amongst other floating molluscs at great depths, chiefly pteropods, the *Valdivia* captured a gigantic *Carinaria* over two feet in length. Of even greater zoological interest were giant specimens of the *Appendicularia,* which were taken at between 1100 and 1200 fathoms. This creature, named by Chun, *Bathochordæus charon,* reaches a length of about five inches, and has in its tail a notochord as big as a lamprey's. All other genera of this group are minute, almost microscopic.

There are two other peculiarities common amongst the deep-sea fauna which are difficult to explain. One is a curious inability to form a skeleton of calcareous matter. The bones of many abysmal fishes are deficient in lime, and are fibrous or cartilaginous in composition. Their scales, too, are thin and membranous, their skin soft and velvety. The shells of deep-sea molluscs are as thin and translucent "as tissue-paper"; and the same is true of some brachiopods. The test of the echinoderms is often soft, and the armor of the crustacea is merely chitinous, unhardened by deposits of lime. Calcareous sponges are altogether unknown in the depths. This inability to form a hard skeleton — curiously enough this does not apply to corals — is not due to any want of calcareous salts in the bottom waters. It is known that calcium sulphate, from which ani-

mals secrete their calcium carbonate, exists in abundance; but those animals which dwell on the calcareous globigerina ooze are as soft and yielding as those which have their home on the siliceous radiolarian deposits. Animals which form a skeleton of silex do not suffer from the same inability; in fact the deep-sea radiolarians often have remarkably stout skeletons, whilst the wonderful siliceous skeletons of the hexactinellid sponges are amongst the most beautiful objects brought up from the depths.

The second peculiarity, for which there seems no adequate reason, is the reduction and diminution in size of the respiratory organs. Amongst the crustacea, the ascidians, and the fishes this is especially marked. The gill laminæ are reduced in number and in size; and the evidence all points to the view that this simplification is not primitive but acquired, being brought about in some way by the peculiar conditions of life at great depths.

When the first attempts were made to explore the bed of the ocean, it was hoped that the sea would give up many an old-world form; that animals, known to us only as fossils, might be found lurking in the abysmal recesses of the deep; and that many a missing link would be brought to light. This has hardly proved to be the case. In certain groups animals hitherto known only as extinct, such as the stalked crinoids and certain crustacea, e.g. the Eryonidæ, have been shown to be still extant. The remarkable *Cephalodiscus* and *Rhabdopleura,* with their remote vertebrate affinities, have been dragged from their dark retreats. Haeckel regards certain of the deep-sea medusæ as archaic, and perhaps the same is true of some of the ascidians and holothurians; but, on the whole, the deep-sea fauna cannot be regarded as older than the other faunas of the seas. The hopes that were cherished of finding living ichthyosauri or plesiosauri, or the Devonian ganoid fishes, or at least a trilobite, or some of those curious fossil echinoderms, the cystoids and blastoids, must be given up. Certain of the larger groups peculiar to the deep sea have probably been there since remote times; but many of the inhabitants of the deep belong to the same families, and even to the same genera, as their shallow-water allies, and have probably descended in more recent times. There, in the deep dark stillness of the ocean bed,

unruffled by secular change, they have developed and are developing new modifications and new forms which are as characteristic of the deep sea as an alpine fauna is of the mountain heights.

UTILIZING THE SUN'S ENERGY.*

By ROBERT H. THURSTON.

MEN of science, familiar with the resources of our globe in the domain of power production and utilization, and especially all who have considered the origin, extent, and rate of extinction of the quantities of energy available for the purposes of civilized humanity, have, for many years, concerned themselves seriously with the question, "When and how shall we reach and pass the critical period at which the stores of now available latent energy of fossil fuel shall have become exhausted?"

While this problem is not immediately pressing, it cannot be long, time being gauged by the periods of the historian,— it is still more limited in the view of the geologist,— before our stock of coal will be so far depleted as to make serious trouble in our whole social system. Professor Leslie, when State geologist of Pennsylvania, and the late Mr. Eckley B. Cox estimated the probable life of the coal supplies of that State, at the present rate of consumption and acceleration, to be something like a century, and the close of the twentieth century will be very likely to see an end of such manufactures in that State as depend upon cheap fuel and proximity to the coal deposits. In Great Britain the case is probably vastly more serious than in the United States, for there the coal beds are far more restricted in area, and in many localities are already extensively depleted, with prices rising as a consequence. The same is to be said, in perhaps somewhat less degree, of the fuels of the Continent of Europe, and France, and particularly Germany, may ere long feel the effect of a stringency in the fuel market.

Enormous deposits of coal remain untouched in other sections of the globe, and China can probably supply the world for many

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years; but a time must come, and that within a few generations at most, when some other energy than that of combustion of fuel must be relied upon to do a fair share of the work of the civilized world, and this will probably by that time mean the whole of the world.

Water power, which is the next most important source of energy in manufactures, will do much for us, and that will last as long as humanity survives on this globe; but it is doubtful whether it can be considered as a possible complete substitute for steam power. Yet the total available water power of the world will greatly ameliorate the difficulties likely to arise from extinction of fuel supplies. The mean annual rainfall of the world is 36 inches a year, and this means about 50,000,000 cubic feet per square mile per annum falling on the land of both hemispheres. Taking the mean available height of fall as 10 feet, and assuming it possible to store the water effectively in ample reservoirs, this would mean $500,000,000 \times 60 = 30,000,000,000$ foot-pounds of available energy, and, if expended in three thousand working hours, it would give a total of 10,000,000 horse-power per square mile for such countries as might be able to utilize such a fall. This, however, is but a small fraction of the inhabited area of the globe. As a fair estimate, the data for the Mississippi River, in the United States, may be taken. This stream drains about 1,250,000 square miles, with a rainfall of 30,000 inches, an average, for each foot of fall, of 11,000,000,000,000 foot-pounds per annum. The fall is 6 inches per mile, average, and the energy capable of use for that area is about a quarter of a million horse-power per square mile.

These figures are enormous, and give the impression that we need not feel uneasy about our power supply, even though we entirely extinguish our fuel deposits. They are, however, of little value; for they give no idea of the practically available energy of rainfall, since it is not possible to make use of more than a minute fraction of this total, and it is not at all probable that we ever can. In the whole length of the Mississippi River there are but three available water powers, one with 78 feet fall at Minneapolis, one with 24 feet at Des Moines, and one with 22 feet at Rock Island. Taking the average flow as a half million cubic feet per second, utilized, the water powers at

these points would be a total of about 7,000,000 horse-power, derived from an area of a million and a quarter square miles, and directly from but a fraction of that area, situated above the lowest fall.

The deduction must evidently be that water power alone cannot be depended upon to provide the energy that will be needed by future generations should fuel be unavailable, although it is equally obvious that streams are likely to provide immense quantities of power, and that manufactures, in those coming days, will group themselves about the mill sites or within distances from them which can be spanned by the electric high-tension wire. Of this process of displacement of manufactures, Niagara and Buffalo are already giving impressive illustrations. As time goes on the part to be taken in power production by waterfalls will become increasingly important. It is already vastly greater and more important economically than is generally supposed. There are known water powers in the United States, able to furnish, if fully utilized, something like 200,000,000 horse-power; Niagara, at the falls alone, can supply between four and five millions and a considerable additional quantity from the rapids, above and below the falls, and numerous other water powers distributed over the hilly and mountainous portions of the country will, in time, no doubt, become centers of power production and distribution. The one threatening aspect of the hydraulic power problem is the extreme probability that the continued destruction of forests and vegetation will make the streams more and more unreliable for continuous supply.

Wind power is another source of available energy, like water-power, deriving its origin from the energy of the sun's rays, which may, as time goes on, provide a continually larger amount of utilizable energy for the use of mankind; but it is subject, even in greater degree than water power, to the objection that it is variable and unreliable for steady work. The winds are continually rising and falling. "As variable as the winds" well indicates the uncertainty of atmospheric currents as a source of power for industrial purposes. Rising to a gale and falling to a calm, alternately, the portion of the time during which this power is actually available is small, and still worse, its available periods are as likely to come at unsuitable hours

and seasons as when wanted. There is ample wind power for all purposes, undoubtedly, could it be regulated, stored, and economically availed of; but, while no one can say what may or may not be accomplished by the coming inventor, mechanic, and engineer, it does not seem likely that this particular problem will be successfully solved, even under the stimulus of vanishing fuel supplies.

Tidal power is still another possible source of industrial energy, and one which also has its own and peculiar difficulties of utilization. It is a regular and well-measured and well-known quantity; its hours of rise and fall, and the heights of rise and fall, are well-established; but when it is sought to design a system of utilization that shall be cheap, practicable, reliable, and compact, one that may compete with other power systems, it is found to be a very difficult, and, for the time, at least, impracticable, system of power production.

At the moment, engineers and men of science are studying the art of reducing to harness the direct rays of the sun, and the solar engine is exciting special interest. It is no novelty, and many inventors have, for years past, worked upon this attractive problem; but probably at no time in the past has this matter assumed importance to so many thoughtful and intelligent men or excited so much general interest. John Ericsson, the great inventor and mechanic, when writing, in 1876, the great quarto volume which he intended should be the memorial of his life's work, devoted a very large proportion of its space to the account of his solar engines and of the scientific investigations made in the course of his work for the purpose of ascertaining the amount of power thus derivable from the direct rays of the sun. His apparatus was simple,— merely a conical mirror or reflector, receiving the heat of the sun on as large an area as was desired and was found practicable, and directing it to a focus where was placed a steam boiler or an air cylinder within which the fluid, heated to a high temperature, became available for use in a steam or an air-engine. He reported the results of his experiments thus*: —

"It has already been stated that the result of repeated experiments with the concentration apparatus shows that it ab-

* Contributions to the Centennial Exhibition, by John Ericsson, 1876. D. Van Nostrand, New York.

stracts on an average, during nine hours a day, for all latitudes between the equator and 45 deg., fully 3.5 units of heat per minute for each square foot of area presented perpendicularly to the sun's rays. Theoretically, this indicates the development of an energy equal to 8.2 horse-power for an area of 100 square feet. On grounds before explained, our calculations of the capabilities of sun power to actuate machinery will, however, be based on one horse-power developed for 100 square feet exposed to solar radiation. The isolated districts of the earth's surface suffering from an excess of solar heat being very numerous, our space only admits of a glance at the sunburnt continents.

"There is a rainless region extending from the northwest coast of Africa to Mongolia, 9000 miles in length and nearly 1000 miles wide. Besides the North African deserts, this region includes the southern coast of the Mediterranean, east of the Gulf of Cabes, Upper Egypt, the eastern and part of the western coast of the Red Sea, part of Syria, the eastern part of the countries watered by the Euphrates and Tigris, Eastern Arabia, the greater part of Persia, the extreme western part of China, Thibet, and, lastly, Mongolia. In the western hemisphere, Lower California, the tableland of Mexico and Guatemala, and the west coast of South America, for a distance of more than 2000 miles, suffer from continuous intense radiant heat.

"Computations of the solar energy wasted on the vast areas thus specified would present an inconceivably great amount of dynamic force. Let us, therefore, merely estimate the mechanical power that would result from utilizing the solar heat on a strip of land a single mile in width, along the rainless coast of America; the southern coast of the Mediterranean, before alluded to; both sides of the alluvial plain of the Nile in Upper Egypt; both sides of the Euphrates and Tigris for a distance of 400 miles above the Persian Gulf; and, finally, a strip, one mile wide, along the rainless portions of the shores of the Red Sea, before pointed out. The aggregate length of these strips of land, selected on account of being accessible by water communication, far exceeds 8000 miles. Adopting the stated length and a width of one mile as a basis of computation, it will be seen that this very narrow belt covers 223,000 millions of square

feet. Dividing the latter amount by the area of 100 square feet necessary to produce one horse-power, we learn that 22,300,000 solar engines, each of 100 horse-power, could be kept in constant operation, nine hours a day, by utilizing only that heat which is now wasted on the assumed small fraction of land extending along some of the water-fronts of the sunburnt regions of the earth.

"Due consideration cannot fail to convince us that the rapid exhaustion of the European coal fields will soon cause great changes with reference to international relations in favor of those countries which are in possession of continuous sun power. Upper Egypt, for instance, will, in the course of a few centuries, derive signal advantage and attain a high political position on account of her perpetual sunshine and the consequent command of unlimited motive force. The time will come when Europe must stop her mills for want of coal. Upper Egypt, then, with her never-ceasing sun power, will invite the European manufacturer to remove his machinery and erect his mills on the firm ground along the sides of the alluvial plain of the Nile, where an amount of motive power may be obtained many times greater than that now employed by all the manufactories of Europe."

The probable value of the quantity of energy transmitted to the earth from the sun, according to the conclusion, after extended investigation, of the late Professor DeVolson Wood, the greatest of American thermodynamists of the nineteenth century, is not far from that obtained by Langley,— 133 foot-pounds per square foot of receiving area per second, about $133/550 = 0.24$ horse-power, or the equivalent of 4 square feet per horse-power. As actually utilized, Ericsson reported his solar engine to supply a horse-power from 100 square feet of receiving area, on a bright, clear day, and other experimentalists, with apparently less efficient apparatus, report a horse-power from about 150 square feet in sunshine.

This figure is confirmed by recent experiments at Pasadena, Cal., where it is said that the efficiency reached by Ericsson has in some cases been attained. The California apparatus includes a truncated conical mirror, 33 feet 6 inches in diameter at the top and 15 feet at the bottom, which concentrates the rays of the sun received upon its 1788 facets at a focus where a boiler is

placed, and where steam is made, to operate a steam-engine of small power. The whole mass of glass and iron composing the mirror is moved by a suitably arranged clock, and is automatically held with its axis directed toward the sun. The boiler is carried on the same frame and moves with the mirror. It is 13 feet 6 inches in length, and contains about 10 cubic feet of water and 8 cubic feet of steam space. The steam pressure is carried at 150 pounds per square inch. It is rated at ten horse-power. This power is utilized in pumping water, but the reported figures are inconsistent with its rating. To set the machine in operation it is only necessary to turn the apparatus by hand until its axis points at the sun's disk and to set the clockwork in operation. To stop it, requires simply the turning of the mirror away from the sun and the stopping of the machinery which adjusts it.

The uncertainty which the engineer feels regarding this type of motor is due largely to the difficulties arising from the fact that the sun is not always available, even by day, and that it is entirely out of reach for power purposes for one-half the twenty-four hours, and he has as yet no idea of practical methods of storage, either of the heat or the power, for use during cloudy periods, hours, days, and weeks even, when the engine cannot be kept in steady operation. It is, of course, possible that much improvement may be effected in the electric storage battery, and it is even true that great improvements in that precious device are apparently already in sight; but even the ideal and perfect battery, could it be realized, would probably prove so costly and so enormous, as a part of this system of sun-power utilization, as to make its use practically out of the question in temperate regions where the sky is overcast so often that not over one-half the direct heat of the sun is each day, on the average, available, or in the tropics where the rainy season makes it unavailable for months together. Where, as may occasionally be practicable, storage may be effected by raising water into extensive and elevated reservoirs provided by Nature, this difficulty may prove less serious; but such exceptional advantages of location cannot be relied upon for any important aid in securing general utilization of the solar motor.

For necessarily continuous use of power, it is thus evident, this system gives little promise, and a cotton mill, for example,

that must go into operation only when the sun comes out from behind a cloud and go out of action the instant it disappears again, can hardly be expected to pay dividends. Water power must be its reliance when coal cannot be employed, rather than either sun power or wind power, and its work must be done where a sufficient amount of fall and flow can be had to meet its maximum requirements, even at the period of minimum flow.

The availability of sunlight and heat for the purposes of the engineer differs greatly in different places, and with every change of latitude, as well as from season to season. This variability is an enormous handicap where it is sought to employ this energy. The remark is attributed to Professor Langley that all the coal deposits of Pennsylvania, if burned in a single second, would not liberate a thousandth part as much heat as does the surface of the sun in that unit of time. Yet it is evident that our coal deposits, so long as they last, are worth more to us than all the available heat of the sun.

In conclusion, we may thus make the following deductions: —

The rapid and rapidly increasing destruction of our stores of mineral fuel must, sooner or later, bring us to a point at which it will be no longer possible to derive the power required, in the arts, from that source.

That period is likely to be ushered in before many generations, and is, in fact, in some portions of the world already presenting its preliminary symptoms,— difficulty in mining and increased price of the fuel in the market as well as the expressed anxiety of statesmen guarding the interests of the great manufacturing districts of Europe.

The ultimate outcome must be the gradual extinction of our fuel supplies, and if no substitute can be devised by the ingenuity of man, the compulsory retreat of the civilized races into the tropics, and, even there, the interruption of the manufacturing industries on the scale necessary to the maintenance of civilized life as we know it to-day.

While it may be true, as has recently been estimated, that the belt extending thirty degrees on either side of the equator may be capable of sustaining a population of ten thousand millions, over ten times the number now inhabiting that portion of the globe, such a population will require correspondingly increased

power supplies, if it is to be a civilized population as we to-day define the word.

The available sources of power remaining are wind and water power, and the utilization of the energy of the direct rays of the sun. The last, though apparently most universally available, has hitherto been unused, while the indirect systems of employment of the sun's energy have been very extensively employed, the deduction being that the former process presents elements of peculiar difficulty.

Water power is, to date, the most available, and the common substitute for the heat-engine. When the existing waterfalls are generally utilized, they will go far toward meeting the needs of the race in power production, and the coincident use of the electric current for the distribution of energy from its source is now making this element of the problem far more promising of solution than previously. Yet it is doubtful whether water power will suffice for all the requirements of later generations, even though the usual result of stimulated brain work, checking of the growth of population, should hold down the numbers of the human race to something like those of the present time.

Wind power, although even more generally distributed than water power, is subject to its own peculiar disadvantages for our purposes, and, while likely to come more and more into use for purposes like that of raising water to higher levels, and where steadiness and continuity of action are not important, will probably be found in great part unavailable for large powers or for the great majority of uses which commonly demand steadiness of power and action.

Solar motors make available an immense quantity of active energy by direct utilization. They are evidently practicable in the sense that there is no inherent mechanical difficulty in their construction and operation. They are subject, however, to the same defects of lack of steadiness of source of energy, of need for provision for extensive and prolonged storage, if to be generally employed, and to the serious objection of large cost per unit of power delivered. Whether this cost will be so great as to balance the gain coming of free delivery to the machine of the energy to be transformed can be known only when we are

driven to the serious task of providing substitutes for the heat engines.

Ericsson made a working steam-engine deriving its energy from the direct rays of the sun, and proved that either steam or air could be employed in such an engine as the working fluid. He also showed what is the amount of power practically derivable from the sun's rays through this method of utilization of the heat of the sun.

Later testimony, so far as it goes, confirms his statements, and the mechanical possibility is beyond question that, in future centuries, when our fuels are gone, we may largely utilize the sun's energy in this manner. But it may yet be found that this threatened exhaustion of our fuel supplies is not the only, or perhaps even the first, limit likely to be set to the progress of the world of humanity on our globe. The exhaustion of our iron ores, like our platinum deposits, the mingling with the air of the products of combustion of our fuels while they still last, the pollution of our water supplies, and many other possible obstacles to progress and growth, will have their effects, individual and combined, and our most serious problems are quite likely to be found at an earlier date than that of the loss of our fuels; the last-named danger is, in fact, already upon us. This generation need not attempt to cross the first of the bridges on the list, although a very seductive problem is presented to the engineer. This problem may be enunciated thus: —

To find a system of gathering and storing the energy of the direct rays of the sun, for utilization in power production, by a special form of heat-motor; to find, next, a method of transforming the energy thus collected into mechanical power; and to discover a method of storing, for later use, excess power obtained during periods of sunshine, tiding over the sunless periods.

The problem will be solved only when the system thus perfected is so designed and constructed as to be able to provide power for industrial purposes so cheaply that a business profit can be made through its use.

WONDER-WORKING INVENTIONS.

By ALEXANDER HARVEY.

GREEN, the great historian of the English people, complained eloquently, years ago, of the exclusive attention paid by human annalists to the business of the court and the camp. To him it seemed clear that the story of a nation must be the story of its people as well as a record of its immortal statesmen and of the decisive battles it has fought. In Green's pages, therefore, we learn how, from century to century, the people of England fed themselves, how they lighted and heated their homes, what they wore and their modes of travel through the land. Now, it would be exaggeration to say that Green was a pioneer in a domain never previously explored — for Macaulay, not to mention others, had invaded it before him — but he was the first great historian to understand how much of human history has been made by the inventor. All the great social revolutions of the last century, thinks Froude, were achieved by inventors, and it is difficult to read such a history as that of Green's without coming to the same conclusion.

Opinions will, naturally, differ as to the precise importance to mankind of any one among several inventions that may be fairly termed epoch making. It is beyond dispute, for instance, that the introduction of the art of printing into western Europe had effects upon the destinies of our race as momentous as those of the battle of Marathon. But how are we to determine the relative importance of the discovery of antiseptic surgery? That miracle of medical science has revolutionized the life of every civilized community. But the influence of the invention of printing upon the life of every man, woman and child in the world is a direct one. Antiseptic surgery affects each of us indirectly — more or less. Green and Macaulay seem to agree that those inventions which directly influence the course of our

every day lives — those which relate to our food and our clothing, our light and our letters — have really wrought the social revolutions which make civilization what it is.

This theory, if sound, narrows the area of dispute, certainly, but it leaves much room for disagreement. The importance attributable to any invention depends upon the point of view. The five supreme names in literature, says Lowell, are those of Homer, Dante, Shakespeare, Cervantes and Goethe. The five great captains of the world, thinks Jomini, are Hannibal, Alexander, Julius Cæsar, Frederick the Great and Napoleon. But from what fields of invention shall we choose five great names to go with these? Close, indeed, would be a competition between the inventor of the mariner's compass and the discoverer of the circulation of the blood, the inventor of the power loom and the inventor of the electric telegraph, the originator of the locomotive and the pioneer of the steamboat.

Green, clearly, has blazed the best path through this forest of controversy. The inventions that have wrought social revolutions are the inventions of first importance from the every day point of view of the practical man. The list is still a long one, and there is no need to exhaust it. Our concern is with those only which have vitality and a future in the life of the twentieth century. An invention may have immortalized a man and have survived to a green old age, but it would be aside from the purpose to pen its obituary here. The inventions which are doing more and more of the world's work, not those which are doing less and less of it, call for the study of the twentieth century bread winner.

Testing contemporary inventions, therefore, by the law of the survival of the industrially fittest, we find some seven or eight great weapons in the arsenals of the captains of industry. They are the cotton-gin, the sewing machine, the reaper and thresher, the rubber manufacturing process, the typewriter, the cylinder printing press and the typesetting machine. Each of these contrivances is directly influencing the daily life of every civilized man, woman and child. Each, in its way, has wrought a revolution as radical as that which followed the expulsion of the Tarquins or the fall of the Bastile. Macaulay tells us that Eli Whitney, the inventor of the cotton-gin, did more to make the United States a mighty nation than was ever accomplished by

Peter the Great for the elevation of Russia to the rank of a great power. The winning of the west, in the pioneer days of this republic, did not make the wilderness to blossom as the rose until the advent of the McCormick reaper, which has been styled "the greatest of expansionists." Guizot thought the cylinder printing press the father of universal suffrage, while wide circulation has been given to Charles Reade's saying that he would feel less anxiety regarding the future of a son of his who understood the typewriter than a son who understood Latin or Greek. However, in pronouncing a panegyric upon Goodyear, the perfector of the rubber product, Joseph Holt, one of the most famous of our country's Patent Commissioners, paid a tribute sufficiently comprehensive to embrace all the achievements which, like those now to be considered, added a new world to an old one as certainly as did the immortal voyage of Columbus. "The fruits of the inventor's genius," wrote Holt, in his estimate of Goodyear, "will endure as imperishable memorials and, surviving the wreck of creeds and systems, alike of politics, religion and philosophy, will diffuse their blessings to all lands and throughout all ages."

The stories of these men — the Howes, the Whitneys, the McCormicks — are not less wonderful than their achievements. They read like modernized tales of the bold Spanish conquistadores or fantastical imitations of the Arabian nights. In the good, old fashioned style, we follow our hero through poverty and obscurity until, transformed into a new Aladdin, he has but to rub his lamp — or have somebody else rub it — to create wealth greater than that which Pizarro bore back to Spain. We are lifted from an abyss of despair to a climax of triumph as thrilling, as moving to the imagination, as that immortalized by Keats in the most famous of all sonnets:

> "Then felt I like some watcher of the skies
> When a new planet swims into his ken,
> Or like stout Cortez, when with eagle eyes
> He stared at the Pacific, and all his men
> Gazed at each other with a wild surmise —
> Silent upon a peak in Darien."

HOW THE COTTON-GIN ESTABLISHED THE GREATNESS OF THE SOUTH.

When Eli Whitney was born in the little Massachusetts town of Westborough, in the year 1765, that famed and splendid

region to which we Americans give the name of "The South" seemed, to all human appearance, on the eve of a melancholy decline. The fine old gentlemen of Virginia still went about in their coaches and six, dispensing a hospitality to which the high price of tobacco, the swarms of black slaves and the virginity of the soil imparted both luxury and lordliness. Great estates yet flourished along the coast, especially in South Carolina, where plantations of rice, indigo and corn had created an aristocracy as exclusive as that of contemporary Vienna. But the spirit of these proud people was everywhere heavy with a sense of impending catastrophe. The weight of mortgages was growing more and more burdensome. The possession of a great estate had become a source of embarrassment. The interior of the country did not fill up. The thriftier white inhabitants were looking to the west, while the heads of the great families grew lonelier with the passing years, which brought them diminished profits and accumulating debts. "Poor old Virginia!" exclaimed John Randolph, the last of a long line of slowly ruined tobacco lords. "Poor old Virginia!" And it did seem, for some dark years, as if the Old Dominion were but heading some stately procession to the almshouse.

What made the situation the more tantalizing was the prolific exuberance with which the cotton plant spread itself over so many of these debtor states. Civilized man had begun to call for cotton, while in the one region where this plant really thrived its culture was a source of despair. The constant labor of the most industrious slave barely sufficed for the production of a single bale of cotton after three months of laborious separation of the fibre from the seed. The difficulty lay in this work of extracting the seed from the cotton itself. Meanwhile, over in England, a factory hand, Arkwright, introduced an invention that was to change the face of Lancashire. But Arkwright's power loom was still waiting impatiently until the planters of the cotton-producing regions had been provided with means of overcoming the sole barrier between themselves and opulence. It would, of course, be the idlest platitude to observe that not one of these fine southern gentlemen remotely dreamed of the existence of the little lad in far-off New England who was yet to make them all rich and powerful and himself the greatest of sufferers from man's ingratitude.

As Eli Whitney grew up on his father's farm, the inventiveness he displayed on all occasions made him famous for miles around before he was out of his teens. He was the only boy of twelve in all Massachusetts who could put a watch together after having taken it to pieces, and whose fiddles, entirely the work of his own hands, could be sold for money in the great city of Boston itself. He monopolized the local nail trade when he was fifteen, and in a few more years his profits as a maker of knives, pins and tools, turned out in his evening's leisure when the day's labor on the farm was done, enabled him to go to Yale. Here he gave a new lease of life to the philosophical apparatus by the execution of sadly needed repairs, but, instead of proceeding to Boston upon his graduation, as might have been expected, he accepted an engagement as tutor in that remote region of the earth known as Georgia.

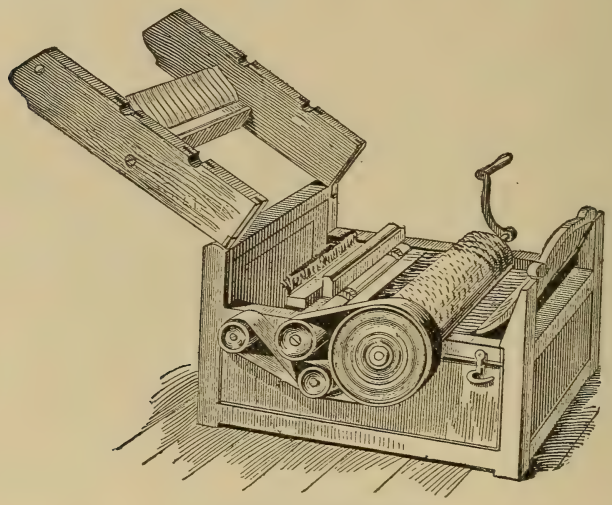
The South was a long way from New England in 1790, and when Whitney reached the great plantation he learned that the post of tutor, which he came so far to fill, had been given to another. His plight was a sorry one, and, when information of it reached the widow of a revolutionary hero, then residing on the Savannah River, she provided young Whitney with a home on her estate. He now made up his mind to study law.

But Blackstone can no more suppress an inventor than he can crush a poet. The lady who had so opportunely come to his aid was speedily repaid a hundredfold by the utility of the innumerable contrivances with which Eli Whitney met every one of her domestic emergencies. He rejuvenated all the antique mechanism on the estate and turned out knives, tools and even engines that surpassed in neatness and utility the high-priced importations from London. His friend speedily saw in her young guest the eighth wonder of the world and when one day she begged him to invent the cotton-gin she felt all a woman's implicit confidence in the genius of her hero. "Eli Whitney," explained Mistress Greene, "can make anything."

She was addressing a convivial gathering which, in the lavish fashion of those spacious southern days, had assembled about a well spread table to be attended by a multitude of slaves. To anyone but Eli Whitney the lady's perfect faith might have presented a few embarrassments. Cotton seed he had never beheld, for it was not yet in season. Wire, which he at once

perceived to be the first requisite, could not be procured in any part of Georgia then. The plant itself was not in bloom. What tools he might require he could not even guess. In any event, he must make them himself. Under such auspices the young man from New England set to work.

It took weeks of spider-like patience to fashion the tools and draw the wire, months to obtain sufficient cotton for the first discouraging experiments with hopeful gins that stuck fast and turned out failures when they gave most promise. The object to which Eli Whitney was devoting his leisure inspired a few wags in the state to jest at his expense. But that New England



The First Cotton-Gin.

conscience of his could not give up. At last he had made a cotton-gin.

What a breathless moment when his triumph was finally revealed to a group of his hostess' guests, who trooped over from the mansion to Eli Whitney's workshop! They saw a contrivance like a crated mangle. It was, in essentials, a long cylinder provided with a succession of circular saws, the latter projecting just enough to catch the cotton fed through a hopper. When Whitney turned the handle, the saws gripped the cotton and rejected the seed, which was not small enough to get by. But at the climax of the enthusiasm which the sight inspired, there

happened another of those unfortunate accidents. The cotton became packed too tightly in the teeth of the saws and the gin stopped short. One of the ladies seized a brush and cleaned the teeth. The hint was enough for Whitney. He added a cylinder of brushes to the cylinder of saws and the South of ante-bellum days was started on its great career. No subsequent improvement modified the essential principle of the cotton-gin.

The first effect of the Yankee youth's invention was to confer immense importance upon the slave. The vastness of the cotton agriculture that spread throughout the South, stimulated by improvements in England's spinning and weaving machinery, had momentous consequences because the importation of slaves into the United States was prohibited by the constitution after 1808. Now, the cotton-gin, augmenting the demand for slaves, immensely influenced those southern states, which grew no cotton, but which tolerated slavery. These were transformed into slave-breeding states, and were made feeders for the cotton plantations. Jefferson's hope that slavery would die a natural death perished with the advent of the cotton-gin. It gave rise to two conflicting social systems within the union. The vast estates of the southern plantation magnates became a source of solvency instead of a source of debt. Black slaves and white dependents created that influential class of southern statesmen who for some fifty years held sway in this republic and who strove at last, through civil war, to maintain a social system which seemed to them the only true one for the cotton belt. The long and terrible conflict which seemed in the dark days of Lincoln's administration to be rending the republic asunder can be traced directly to the cotton-gin upon which Eli Whitney expended so much of his inventive genius.

And he, like the ungrammatical sailor of Kipling's poem, could exclaim: "It never done no good to me!" There was a rush to duplicate his cotton-gin, the simplicity of the contrivance lending itself to evasion of Whitney's rights as inventor. Patent laws were chaotic in those days and courts were not over nice in their rulings. One or two state legislatures in the South voted small sums to Whitney, who, after years of disappointing law suits, finally went back to New England and turned his talents to firearms. He was well-to-do when he died in 1825, and his name can never be forgotten, for he is the only inventor who brought on — innocently enough — a civil war.

THE SEWING MACHINE ABOLISHES A FUNDAMENTAL CLASS DISTINCTION.

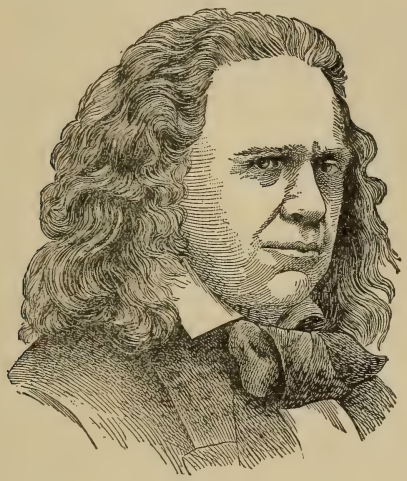
In this effervescent twentieth century, every youth who longs for the favor of that great god, success, is told to dress well. It is no very difficult thing to do nowadays, even though one be poor. That great journalist and student of social problems, the late Edwin Lawrence Godkin, was of opinion that what he called "the note of quietness" in men's attire had caused a far-reaching revolution by abolishing a fundamental class distinction.

Mr. Godkin's theory is strikingly confirmed by the state of fashion in this country as recently as the administration of President Jefferson. In those days the mere mechanical labor involved in sewing a man's coat and shirts made neatness of attire a class distinction of the most decided kind. A man's social importance rose with the number of seams in his garments, and if we go back as far as the days of President Washington, we find the ruffle and the hem regarded with the awe now reserved for the automobile and the coat of arms. That revolutionary hero, John Hancock, boasted of the endless stitching involved in the production of his least flamboyant waistcoat, while the humble artisan of that era was content to swathe himself in what, for want of needlework, resembled an assortment of coal bags.

The great change that has been wrought since then is due to the sewing machine, the mighty equalizer of opportunity in all that relates to the attire of mankind. An English economist asserts that if the workingmen of Great Britain would cease the purchase of beer and tobacco they could all afford to dress better than peers of the realm usually do. That was not the case when the inventor of the sewing machine was a boy.

His name was Elias Howe and he was born in Spencer, Massachusetts, in 1819. His lot in life was that of the factory hand, and he began to work when he was only six. He was noticeable, in spite of his sickliness and lameness, for graciousness of manner and for good looks much above the average. But he does not seem to have been the kind of lad who goes home when the day's work is done and pores over books. On the contrary, he was thought rather idle and a little incompetent. As he grew up, he drifted aimlessly from mill to mill and at last he got married.

By the time he had three children he was next door to a pauper, the labor of the wife being one of the barriers between himself and starvation. He was such a physical wreck at this time that when he got home from work he would lie down for the rest of the evening, while his wife, who was going into consumption, stitched until the night was far gone.



Elias Howe.

Howe, whose career had by this time confirmed the impression of the few who knew him that he was "shiftless," was of what is called an inventive turn of mind. Before he broke down he would spend hours of his leisure in the contrivance of spinning and weaving mechanisms and in haunting the workshops of inventors as poor and as hopeless, for the most part, as himself. And as he watched his wife at her sewing, night after night, he would say how pitiful it seemed that such monotonous, mechanical toil should have to be done by hand.

This idea gave him no rest. Howe did not know that other minds had attacked the problem before him. He had never heard of the Thomas Saint who, a hundred years before himself, made a machine that sewed and relapsed into oblivion. Yankee inventiveness had likewise wrestled with mechanical needles, operated by shuttles and lathes. One of these would even sew leather. But they all came to nothing.

So Howe went to work as a pioneer. There was no past experience by which he could guide himself to success. He made up his mind at the start that fine thread could never be used in a sewing machine. Next he concluded that the needle would have to be pointed at both ends and have the eye in the middle. Finally, it appeared to him that a practical sewing machine must imitate the movements of the human hand plying a needle.

Having framed these hopeful hypotheses, Howe set to work. After two years of dire poverty and ill health, spent in experimenting, he produced a mechanism which, with the aid of stout cord, imitated sewing in a rudimentary way. The friends to whom he showed this triumph referred to him sorrowfully behind his back and tapped their foreheads with much significance.

"One day, in the midst of his meditations," writes Charles Kent, with whose vivid account we shall conclude this story of Howe, "the thought startled him — need the machine, after all, imitate the movements of the fingers? Might not there possibly be a different and yet an equally effective stitch? Following up these reflections, the notion occurred to him that with the help of two threads instead of one the design arrived at might be effectually accomplished. To bring these two auxiliary threads into play, he thought first of the Curved Eye-pointed Needle, and in the next place of the aërial Shuttle. By the October of 1844, he had made clear to himself with a rude model of such rough materials as wood and wire, that a Sewing Machine such as he was now dreaming of, might be readily manufactured.

"Fixing his thoughts thus upon his self-appointed task at every possible opportunity in the midst of his daily grind as a handicraftsman, Howe at length, by the December of that year, saw his way so clearly to the realization of his long-cherished day-dream, that he determined not only to quit Boston but at the same time to abandon all his usual avocations — so that he might in point of fact, from that time forward, give himself up entirely to his one all-mastering enterprise. Having resolutely made up his mind to this new course of life, he thereupon took possession of a particularly small, low garret in the house of one Mr. George Fisher, a newspaper publisher and coal merchant, in Cambridgeport, Massachusetts. Shutting himself up there in complete seclusion, Elias Howe applied his subtle intellect and his supple

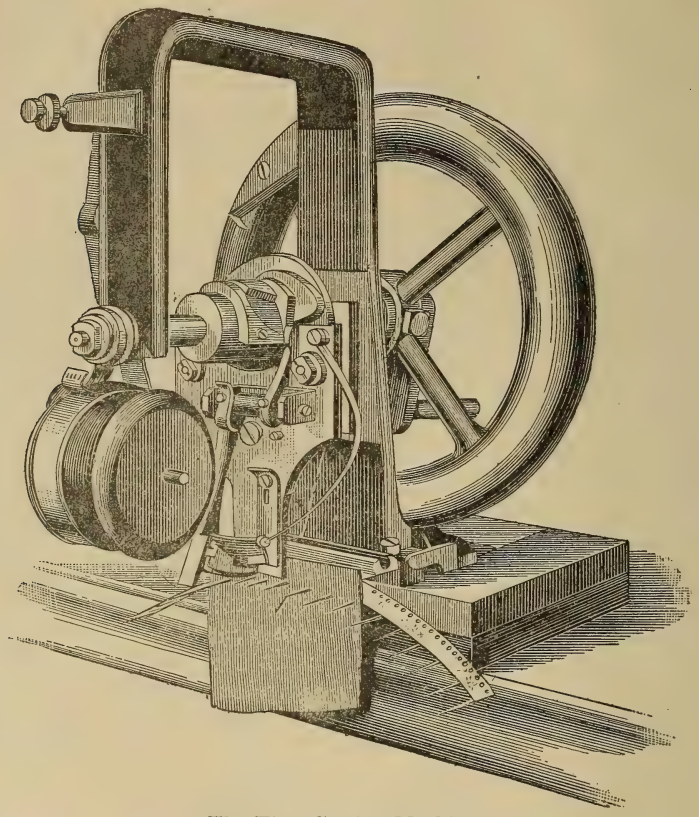
hands, early and late, to the imparting of the last finishing touches to his marvelous little piece of mechanism. Four months of intense application brought to him at length his long-looked-for reward.

"In the April of 1845, the young inventor, being then just twenty-six years of age, by sewing a seam with his contrivance, vanquished his last mechanical difficulty in his garret at Cambridgeport. Emerging from it, he brought out with him perfect and entire — the work of his own brain and the work of his own hands — a Sewing Machine which, in obedience to the turning of a handle, ran off, with mathematical accuracy and with dazzling rapidity, 150 lock-stitches in half a minute; an average of 30 stitches in exactly double that time being alone possible by means of hand-sewing!

"With that earliest constructed of all sewing-machines — which is still preserved intact, and which is a very small piece of mechanism — a couple of suits of clothes of the very finest broadcloth were with astonishing swiftness put together in the July of 1845, one of which was worn by the inventor himself, and the other by the owner of the garret, who, for giving the man of genius food and shelter there for less than half a year, secured to himself, in return for a nominal sum of $500 one moiety of this extraordinary invention. Consequent upon that rather hard bargain, a patent was taken out on the 10th of September, 1846, in their joint names as the owners of the latest World Wonder. 'Thus,' as the familiar words run, 'bad begins, but worse remains behind.' Eleven days after the patent had been granted to him for his magical contrivance, Elias Howe, driven by necessity, had no alternative but, in return for a nominal sum of $1,000, to assign the other half of his property in it to his father, in satisfaction of the latter's claims upon him for certain small loans of money, and for so much, or rather it ought more correctly to be said, for so little board and lodging!

"Thus, upon the very morrow of the completion of his invention, Howe found himself completely stripped of any chance of securing in the United States themselves, the smallest advantage from its adoption. For a while he was driven to such straits in point of fact, that he obtained employment for an interval as a locomotive engineer on one of the railroads — day after day, for many weeks together, taking charge of his locomotive.

"Alarmed lest he might otherwise fail to reap any further benefit from it whatever, Elias Howe despatched his brother Amasa at once to England to see after his interests in connection with the patent in that country. Thither, in the February of 1847, he himself followed; being followed in his turn a little later by his wife and his three children — Amasa having mean-



The First Sewing Machine.

while parted with the whole of the inventor's rights in the English patent for the modest sum of 250 pounds paid down for them by Mr. William Thomas, a corset manufacturer of Cheapside, in the city of London. Apart from that paltry sum, and a verbal promise which was never fulfilled that the purchaser would pay

to the inventor three pounds for every machine that was sold, the only lure held out to Elias Howe as an inducement to him to cross the Atlantic, had been the proffered payment to him of a weekly wage of three pounds sterling, in return for which the contriver of the Sewing Machine actually came all the way from the new world to the old merely to adapt his wonderful contrivance to the petty requirements of the London stay manufacturer! When those requirements were satisfied the three pounds a week ceased, Howe being then left, in a strange land, completely to his own resources. During the rest of his sojourn in England, which lengthened out to some two years altogether, the inventor was driven to the direst straits, being at one time even thrown into a debtor's prison. Eventually, however, though not until after he had run a gauntlet of a long series of humiliations, he contrived to obtain his passage back to America — landing at New York, before the close of 1849, in a state of complete destitution. Upon the very day after his arrival he resumed his old labors as a journeyman machinist. His cup of affliction was not yet drunk to the dregs, however; for, only a few days after he had settled down to work, he was hurriedly summoned home to Cambridgeport by the news of his wife's alarming illness from consumption. Hastening thither upon the instant, he had the grief of seeing her die in his arms before the close of another fortnight.

"Removing shortly after this great home sorrow to Roxbury in Massachusetts, Elias Howe for four years together, from 1850 to 1853, each inclusive, was engaged in a series of expensive lawsuits against a multitude of persons in various parts of the States who were openly and in the most flagrant manner infringing the rights of his invention. At length, however, in the year last mentioned, at the close of one of these same lawsuits — a crucial one involving more or less the whole of the numerous questions which had been so long in dispute — the verdict was given emphatically in favor of Elias Howe after a trial of no less than three weeks' duration. Judge Sprague of Massachusetts, who adjudicated upon the occasion, decided that the plaintiff's claim was valid, and that the defendant's machine was an infringement. Further than that he insisted in so many words that there was no evidence in this case leaving a shadow of a doubt that for all the benefit conferred upon the public by the

introduction of a Sewing Machine the public was indebted to Elias Howe.

"That decision was the signal for him of a new and most happy departure. On the 18th of May, 1853, there was accorded to him full power to grant licenses, of which within six years from that date he had actually issued over 130,000, yielding him a net return of more than $400,000. Meanwhile, before half that interval had elapsed, he had, on the 1st October, 1855, by the purchase of all outstanding claims, become once more in the United States the sole owner of his patent for the Automatic Sewing Machine. His income from it thenceforth steadily increased until it soon reached an annual sum of $200,000.

"When the American civil war broke out the famous inventor of the Sewing Machine was enlisted as a private soldier in one of the Connecticut regiments: in connection with which circumstance it is mentioned in his regard, as illustrating at once the influence and the patriotism of the once poverty-stricken man of genius, that when the payment of the regiment had been for some time delayed by the government, Private Howe out of his full coffers advanced the necessary money.

"Shortly after the completion of his forty-eighth year, the inventor of the Sewing Machine was decorated with the Cross of the Legion of Honor by the Emperor Napoleon III. But, ten years later, Elias Howe's eventually prosperous career was closed rather prematurely by his death on the 3rd October, 1867, in Brooklyn, the fortune realized by him down to that date being estimated in round numbers at $2,000,000."

GOODYEAR'S CONQUEST OF INDIA-RUBBER.

A melancholy little funeral procession wound its way through wet Massachusetts lanes on a certain rainy morning in the year 1840. The unsparing poverty which had reduced the five mourners to trudge afoot behind the rude little coffin in a rude little wagon was the most poignant element of melancholy in the whole spectacle. The two little children clinging to their mother's skirts were literally in rags. Indigent old age had set its seal upon the grandfather, the vigor of whose senile arm was all that restrained the pauper son at his side from sinking to the earth in the weakness of wasted health. No member of the

family had eaten food that day. The charity of neighbors, upon which these people had subsisted for weeks, must have worn itself out.

The name of the unfortunate man who thus accompanied his child to its last earthly repose was Charles Goodyear. But a short time before he had been released from a debtor's prison, where he had spent the greater part of the five preceding years. The few friends who still interested themselves in the fortunes of so miserable a failure in life protested, in their desire to take the most charitable view of his case, that he was crazy. The nature of his mental failing was summed up in the compound word "India-rubber." On all other subjects he was as rational as any man alive, but the moment the one fatal topic was introduced his reason fled.

Goodyear's career had been of a kind to inspire compassion in the most malignant enemy. Coming into the world with the nineteenth century, and born of a long line of shrewd and ingenious Yankee ancestors, he had been bred to the hardware trade by his father, at one time a prominent Philadelphia merchant. The son started life in the Quaker city with every prospect of success. But a financial panic which spread throughout the south in the thirties compelled the Goodyears to call a meeting of their creditors. The firm, gallantly undertaking to pay a hundred cents on the dollar, slid at last to the bottom of the hill of bankruptcy. Charles Goodyear felt that the family must get out of hardware.

The Goodyears had always been an inventive lot. They gave a new hay fork to the world, and chancing to see a life-preserver one day, Charles wondered if the family might not give a new life-preserver to the world. Spurred by the thought of becoming solvent once more, Mr. Goodyear evolved an article from the product of the gum tree and hied with it to New York.

His experience in that metropolis gave the lie, in striking fashion, to all the stories he had ever heard regarding the obstacles in the way of inventive genius. Not only did the head of the first great rubber manufacturing company to whom he exhibited his model receive him with the utmost cordiality, but Mr. Goodyear was also assured that his invention would be an instantaneous success and he was implored to invent something more.

The fact is that, without knowing it, the bankrupt Philadelphian had accomplished the feat known nowadays as seizing the psychological moment. The whole rubber industry of the United States, although flourishing at that time like a green bay tree, was threatened with destruction root and branch. The people had begun to rebel against rubber boots which collapsed in the heat of a summer day to a mass of glue so malodorous as to necessitate burial or froze in the depth of winter to the rigidity and weight of cast iron. The great warehouses of the manufacturing companies were filled with an unsalable product, and Charles Goodyear was told that if he could solve the problem thus presented fame and fortune would be his.

Eagerly he undertook the task. The effect upon his fortunes has been told.

It is no doubt a very fortunate thing for the world that no amount of obloquy and discouragement suffices to defeat the purpose of the inventor of true genius. Otherwise, Charles Goodyear might have been swerved from what he regarded as a divinely appointed mission by the entreaties of father, wife, friends. His descent into poverty and wretchedness was not less trying because of his conviction that he had contrived, by constant study and experiment, to find the solution of the problem to which he had devoted his life and talents. The combination of India-rubber and sulphur, mixed in due proportions and subjected to heat at the proper moment, had brought success within his grasp, and conferred a new industry upon the world in a period of great commercial depression. "His product," says James Parton, the most accomplished of Goodyear's biographers, "had more than the elasticity of India-rubber, while it was divested of all those properties which had lessened its utility. It was still India-rubber, but its surfaces would not adhere, nor would it harden at any degrees of cold, nor soften at any degree of heat. It was a cloth impervious to water. It was paper that would not tear. It was parchment that would not crease. It was leather which neither rain nor sun would injure. It was ebony that could be run into a mould. It was ivory that could be worked like wax. It was wood that never cracked, shrunk nor decayed. It was metal, elastic metal, as Daniel Webster called it, that could be wound round the finger or tied into a knot, and which preserved its elasticity almost like steel.

Trifling variations in the ingredients, in the proportions and in the heating, made it either as pliable as kid, tougher than ox-hide, as elastic as whalebone or as rigid as flint."

Yet we must not hastily infer that a man who could establish a claim upon the attention of his fellow creatures by exhibiting a product so miraculous was on the threshold of wealth and happiness. Many a weary month passed before the capitalists whose offices he haunted could be brought to believe in his perfect sanity. India-rubber was synonymous in the industrial world of that day with failure and fraud. People turned with suspicion from any article into the composition of which India-rubber was alleged to enter. When Goodyear produced at last an India-rubber coat that kept out the rain, and rubber shoes that could be worn, more than one skeptic doubted the evidence of his own senses.

Let us try, for a moment, to imagine twentieth century conditions without the products into which the "gum-elastic" of Goodyear enters. The whole drug trade would go back to its primitive infancy. The automobile and the bicycle would be impossibilities. The transformation of the Congo region from a tropical jungle into a great empire is the work of Goodyear's invention. The destinies of the South American continent were shaped anew by him. He modified the tactics of contending armies in the field by enabling them to take every battery of artillery into action dry in the teeth of a pouring rain. He accelerated the steam engine with rubber belting and abated the zeal of the elephant hunter by providing a cheap substitute for ivory. He brought the rain coat within the reach of the person of moderate means and he fathered antiseptic surgery.

Wasted to a shadow by organic disease, his persevering spirit dauntless to the last, robbed by many who owed their fortunes to the knowledge he had martyred himself to acquire, Goodyear died a poor man in the sixtieth year of his age, leaving a widow and six children without means of support.

McCORMICK'S REAPER WINS THE WEST.

Cyrus H. McCormick, the inventor of the first reaping machine to win its way, was a keen and cautious man of business. Throughout his life he said little, thought much and succeeded

always. He was never really in poverty in his life, and at his death he was a very rich man, while his name was known in some of the remotest regions of the globe.

The McCormicks came originally from the north of Ireland, and they settled in this country early in the eighteenth century. When Cyrus was born in the year 1809, the family possessed several farms in Virginia, owned and operated grist and saw mills and had blacksmith shops, carpenter shops and machine shops. The McCormick of them all was Robert, the father of Cyrus, known all over that part of the country in those days for his honesty, his long Scotch-Irish head and his mechanical turn of mind. He had made a hemp-breaker, contrived a hill plow and devoted much of his spare time to the invention of a reaper.

Cyrus began to work for his father at an early age. Harvesting was laborious business then. Horses and motors did not impel machines through a field of wheat while the scientific agriculturist surveyed the performance from a comfortable seat. The important implements at that time were the farmer's own arms and legs. Cyrus, returning footsore and weary to the house after a day's severe harvesting in the fields, loudly lamented his father's neglect of the reaping machine, long since relegated to oblivion in the barn. The elder McCormick had already come to the conclusion that the principle of his contrivance was too defective to apply to a crop of grain standing in a field.

But Cyrus had once or twice perfected his father's ideas, and he now resolved to see what he could do with that reaper. The old machine was dragged from the obscurity of its fifteen years' retirement and Cyrus, at the ambitious age of twenty-one, looked it over.

The fundamental defect in the whole arrangement, concluded young McCormick, was that it attacked a crop of grain with the weight of its sheer mass. In front of the frame work ran a series of stationary hooks. Over and against the heads of these hooks spun an equal number of perpendicular cylinders. Pins, stuck around the edge of the cylinders, forced the stalks of grain across the hooks and on to the stubble side of the machine, where they dropped in a continuous swathe. Theoretically, the idea was beautiful, but in practice there were too many separations of the grain. The hooks and the pins and the cylinders refused

to co-operate against a tangled crop of grain and persistently failed to deliver the swathe at the stubble side. Cyrus tried and tried, to the edification of grinning rustics, to effect the continuous swathe, but he had always to retire baffled to the barn, dragging behind him a clogged mass of pins, cylinders and hooks. "Si" became the butt of wags in those parts.

But on a beautiful harvest day there occurred in a field of oats an incident of that picturesque kind to which biographers are indebted for their fine effects. Cyrus had announced that he meant to harvest that particular crop and that he would do it with the machine, now born anew. There were no great crowds of spectators, but imagination paints a picture of those skeptic wags, not impossibly gathering to see the fun. "Si" appeared with his reaper, metamorphosed beyond recognition, and the rustic audience hailed him with a laugh. But merriment became wonder when the reaper went through the field and harvested acre after acre at high speed. Young McCormick had triumphed and the performance of that day was destined to be re-enacted in England, France, nearly all the civilized countries in the world, in the presence of men who had come to scoff and who went away converted.

Long study of the workings of his father's machine had convinced young McCormick that ripe grain, standing in the field under ordinary conditions, must only be attacked in bulk. It was too tangled a mass for the various separations of his father's cutting apparatus. It had occurred to the son that the cutting and the arrangement of the grain were best to be effected by the appropriate movements of an edged instrument. In moving against a crop to be harvested by a machine, the right movement, in addition to the forward one of the reaper itself, should be afforded laterally by means of a crank attached to the end of a "reciprocating blade." All reaping machines have since been based upon this McCormick principle.

With a few improvements suggested by experience, the young man next attacked a field of wheat and harvested it. The following four or five years were spent in further study of the invention, for Cyrus McCormick had found that unskilled hands could not equal the results he himself attained. He had made up his mind not to rush into the market too soon. He took out his first patent in 1834, three years after he had cut his first acre

of oats. He resolved, too, that he would be his own manufacturer, and when the time seemed ripe, he enlisted the services of his brothers as agents and managers, finally giving them an interest in his business. It became a very large business soon.

The progress of the McCormick reaper around the world has been triumphant. It crossed the prairies and left great communities to mark its path. Even before the death of its inventor in 1884 it had developed to the point where it cut the grain, piled it upon a receiving platform, conveyed it through the simplest of mechanism to a pair of arms which then gathered the stalks into bundles, bound them neatly and deposited them all in regular order in the field. Yet these several operations involved only the fundamental characteristics of the machine with which young McCormick had harvested his first field of oats. They were the divider, which parted that portion of the grain to be operated upon from the rest of the standing crop, the reel which drew the grain within the orbit of the blade, and the blade whose tremulous motion effected the cutting itself. Such is the combination of ingenuities which has made Argentina one of the granaries of the human race and which in a couple of generations, according to the most eminent of living organizers of agriculture, will convert the uninhabited wastes of Canada into a nation of 30,000,000 people. It has become a mighty factor in the problem of the far east, and upon it European and Japanese statesmen have based their hope of seeing Manchuria and Siberia independent of the outside world, for they will constitute with its aid a world of their own. "No general or consul, drawn in a chariot through the streets of Rome by order of the Senate," declared William H. Seward, "ever conferred upon mankind benefits so great as he who thus vindicated the genius of our country."

HOE SAVES THE GREAT DAILY FROM EXTINCTION.

Polk was president of the United States when the population of this country stunned our grandfathers by attaining the prodigious total of 20,000,000. At that time the city of New York was inhabited by no less than 358,000 people, and the more reckless of the local prophets ventured to affirm that the metropolis would yet have a population of a round million, almost. To

one New Yorker of the period these statistics were a source of great vexation. The name of this man was James Gordon Bennett. He had founded the *Herald* only eleven years before and the newspaper had bounded from success to success. It had risen from the cellar where its founder long sat behind a plank resting upon a pair of barrels and was now disseminating news with a thoroughness and an enterprise that promised to elevate it into a national institution.

Bennett's wonderful career had been one long conquest of obstacles. It cost him a pang, at last, when it slowly dawned upon his reluctant mind that the final obstacle of all was baffling even the inexhaustible fertility of his resource. He could not, in the few hours available for the task, print enough copies of his newspaper to command the immense circulation in sight. His press room was equipped with Hoe's " double cylinders," which turned out some eight or ten thousand *Heralds* an hour, but Bennett's ambition outran that speed entirely. The process of stereotyping, by which all the letters making up a single page of type are cast in one sheet of metal from a mould, was not yet sufficiently advanced to obviate his difficulty. But stereotype plates, if used, would have necessitated a cumbrous duplication of double cylinders in the press room without proving more than a partial remedy of the difficulty. Mr. Bennett's great newspaper was in the position of a bull tied to a stake, and the only consolation was that all the *Herald's* rivals were likewise nearing the end of their respective tethers.

Richard March Hoe, who supplied the *Herald* and its contemporaries with their presses, was keenly alive to the emergency, and everything indicates that he was the only man in a position to come to the rescue. Hoe's life had been spent in the manufacture of huge printing presses. His father had founded a celebrated firm of press makers in England, and the son, who was born in New York in 1812, had made himself a captain of industry by inventing the "double cylinder," long the marvel of the printer's art. But circulations were running away from this invention and no substitute was even in sight.

So, while the *Herald* and its contemporaries were driven to risk their reputations as newspapers by going to press earlier and earlier, Mr. Hoe proceeded to experiment. He expended large sums of money during four disappointing years and was at

last forced to tell the anxious owners of great dailies that his efforts had gone for nothing. But he who sets out on a quest of success is rarely welcome when he comes home with an explanation of failure, be that explanation ever so good. He saw that he had made a mistake and at once began anew.

The solution of the problem dawned suddenly upon his mind in a moment of mental exhaustion, when he was about to throw himself upon his bed after many hours spent in worrying over models. The type must be secured on the surface of a cylinder. Before twelve months had passed, Hoe presses of a new design, equipped with from five to ten cylinders, were rushing sheets of paper past revolving "forms" at the furious rate of fifteen thousand copies an hour. Twenty-five years' further study and experiment had brought the capacity of the Hoe to over twenty-five thousand copies of a newspaper per hour.

Swelling circulations burst even these limits, but it is only the first step that costs and the next one involved less of a crisis. One great roll of paper replaced the separate sheets, and stereotyping had by this time made it easy to duplicate forms on as many other presses as were required. The Hoe press of the twentieth century pastes, folds and counts the largest of daily circulations with a speed that enables the hour of going to press to be postponed until well into the morning.

How direct is the connection between the influence of a "great" daily and the size of its circulation may be open to dispute. But no one will deny that the triumphs of journalism in our day would be unthinkable in the absence of such a press as Hoe evolved. The reporter would be shorn of nine-tenths of his importance. News would be a more perishable commodity than ripe berries. The power of the press, instead of being concentrated, would be diffused, and diffusion of power means loss of energy. Upon the foundation of Hoe's invention was reared the superstructure of publicity, and publicity, declared Gladstone, will be to the twentieth century what revolution was to the eighteenth.

THE TYPESETTING MACHINE AND THE MONOPOLY OF HIGHER EDUCATION.

In studying the lives of men who, like Lincoln, raised themselves from the humblest obscurity to positions of commanding

authority, we are struck, first of all, by the surprisingly small number of books from which they extracted an education. That an ambitious youth, blessed with ability and character, should walk ten miles or labor many weeks to possess a single volume from which to derive his equipment for the battle of life need occasion no surprise to those familiar with the careers of Benjamin Franklin, Andrew Carnegie and a host of others. The noteworthy circumstance is not the privations they endured to come to their books but that they found so very few sufficient. The twentieth century youth, deprived of facilities for attending a great university, cannot hope to make good the deficiency by poring over Plutarch's Lives, an old volume of Shakespeare and an elementary history of the United States. When Lincoln was a lad, electrical science was little better than a superstition, technical education did not make a thousand demands upon the lore and training of skilled proficients, there were no great trunk lines of railway, no network of telegraphs, no great captains of industry clamoring in the market place for the services of educated specialists. When the nineteenth century was young, a half dozen books on a shelf in the corner comprised a more ambitious library than many substantial men felt justified in affording themselves.

We have changed all that, as the French say. The Franklins and the Lincolns of the future are not to-day walking miles in the rain to borrow an old tome. They are fitting themselves for the battle of life with whole sets of books, dealing with subjects of which the best educated men a century ago had little, if any, idea. The field of knowledge has expanded beyond the horizon of the past, and even a cursory survey of it has become impossible without a library at home. Lincoln's allowance of three books spells failure in life to his contemporary emulator, who must have definite ideas about electricity, about history, about chemistry, about literature, about railroads, about the organization of modern industry, unless, indeed, he is to go into the world without prospect of a career. Those are the forms of knowledge which at present connect the individual with the general effort of mankind, and without which he is not really a member of civilization's family at all. The public library must remain an unworked mine to one who has never learned, from the study of a library of his own, to exploit its infinite riches.

Now, the distribution of a set of books among a given number of homes involves a serious mechanical problem at the outset. The quantity of type to be set restricts the size of the projected library within limits of commercial possibility. On the other hand, a set of books adequately covering any field of knowledge, necessarily comprises many volumes. The difficulty of reconciling such conflicting factors was at first thought to have been removed by the typesetting machine. Such great educational movements as that of university extension were indeed, for a time, immensely furthered. But obstacles presented themselves. The mechanical typesetter was a complex affair. Its tendency to break down at critical moments enhanced the original serious cost of its introduction. The face of the type was liable to injury by the clumsiness of the unskilled. The speed of its operation, wherein its grand merit consisted, was often neutralized by the time spent in correcting errors. Finally, the invention did not seem to lend itself to the attainment of the fine results required in book work. For a long time those who conceded the practicability of the typesetting machine denied that it had value outside of a newspaper office.

Among those who refused to be daunted by all these difficulties was a young mechanic of Swiss origin named Ottmar Mergenthaler. He had come to this country when a mere lad and when his school days were over he began the battle of life by acquiring a knowledge of machinery. His inventiveness, while of an original yet practical kind, never brought him large sums of money until accident directed his attention to the subject of typesetting machines. He was once asked, it seems, to perfect a typecasting contrivance and much of his time in the year 1875 — he was then in Baltimore — was thus taken up. His experiments led him to the idea of casting type not piece by piece but in a series, the arrangement of the letters to be effected by the operation of a key-board. Such was the germ of the paradoxical typesetting machine which does not set type.

Eleven years were to elapse before any newspaper proprietor became bold enough to introduce a Mergenthaler machine into his composing room. Experience had disgusted printers with every such thing. But the victory of the Mergenthaler Linotype in 1886 was made good by its subsequent conquest of nearly all the great newspaper offices in this country, the Dominion

and Great Britain. This success is not surprising. The machine makes strips of any practical width, each strip being as high as a piece of type, while the face of the strip bears the lettering which is to be reproduced in print. The invention is operated through a keyboard in front of which the operator takes his seat. A touch of a key upon a "matrix" sends it to its appointed place, there to remain until joined by others. Each matrix, of course, corresponds to an appropriate letter of the alphabet, or to a figure, a character, anything. The matrix letters once assembled like a file of soldiers, and the proper width of the line assured by the introduction of wedge-shaped spaces between the words, all are transferred to a mould. Here hot metal discharges itself over them and a line of type results. The matrices are enabled to find their way home by means of their teeth, which vary indefinitely to keep them from losing their course.

Simple enough in principle, this contrivance had to undergo considerable improvement before it produced a page sufficiently literary in appearance to adorn a book. The solution of that part of the problem dates from 1891, with a superior adjustment of the matrix to the purpose of the electrotyper and the cutting of a letter so clear and so beautiful that an encyclopedia in many volumes turned out by the Mergenthaler is one of the most beautifully printed sets of books in existence. A typesetting machine is now part of the equipment in the book room of every great printing establishment.

There are likewise valuable inventions which do the work of composition by means of actual type. Each letter is a separate piece of metal in the old fashioned way, the setting being effected by the adjustment of nicks to a series of teeth. Such machines must distribute the type when its purpose is served. The Mergenthaler machine, of course, necessitates no distribution, as it practically casts a font anew at every step. But each variety of machine has merits of its own and perhaps it is premature to pick the survivor of them all.

THE REORGANIZATION OF INDUSTRY BY THE TYPEWRITER.

Were the writing machine obliterated from the business life of this country, every great office building in New York and Chicago would have to be torn down. Multitudes of women,

graduated from the pencil and the pad to positions of executive responsibility or of complete independence as heads of business enterprises owned by themselves, would be reduced to practical helplessness. The dominant characteristic of American life, the freedom and independence of woman, might not survive the closing of the avenue to human achievement afforded by this epoch-making and revolutionary creation.

The typewriting machine was no spoiled child of fortune. It struggled desperately for existence against the indifference and misunderstanding of the world. It rose feebly into being from the inventive brain of an Englishman who thought of it two hundred years ago only to let it die the death of discouragement. It revived in another hundred years or more in France and perished. Again and yet again machines that did the work of the pen appeared and disappeared as mysteriously and as obscurely as the ghost of Hamlet's father. France, England and the United States were haunted by these apparitions, vague and unsubstantial, never believed in by men of common sense and unvisionary minds.

No wonder, therefore, that when Carlos Glidden, in the year 1866, remarked to his friend Latham Sholes: "Why can not a machine be made that will write letters and words"? he thought he was suggesting a totally original idea. Sholes and his friend Glidden belonged to that class to which this republic owes as much as it owes to the framers of the constitution. They were inventors. Sholes was trying to make a machine that would page books, that is, number the leaves in regular order. On Glidden's mind was a mechanical furrower of the soil which, he fondly hoped, would transform the plow into a quaint relic of the past. They spent much time in each other's society, and mutual criticism of each other's ideas led to a shock of mental contact which evoked the required inventive spark. Glidden put the mechanical spader behind him and Sholes' enthusiasm for the paging of books was diverted into a wider field of endeavor.

The two friends were immensely encouraged by the result of their first efforts. It is true, their first writing machine was noisier than a coffee mill, it held paper so securely that its subsequent extraction necessitated the display of a high order of expert talent, and the business correspondence of a single morn-

ing could be turned out — in capital letters only — during a period of some three months. On the other hand, the machine did write. The pivoted types set in a circle delivered terrible blows, while spaces between words were not invariably absent. It was a little embarrassing, when the end of a line was reached, to be obliged to wait a day or two while Messrs. Sholes and Glidden, aided by Mr. Samuel W. Soule, who had been let into this good thing, struggled manfully to induce the mechanism to start a fresh line. But difficulties were made to be overcome, as we all know, and Mr. Soule speedily revealed himself as the emergency man of this enterprising trio. Mr. Sholes was made responsible for the spacing, and he faced that responsibility — which turned out to be heavy — like a hero. Mr. Soule had to see that whenever a key was struck a corresponding type-bar responded to the signal, and many a distracted hour did he live through as a result. Mr. Glidden turned out to be a brilliant theorist in all that related to the invention, but he was not otherwise practical. As the original suggester of the whole idea, he was deputed to watch the proceedings of his associates and encourage them with criticism.

These three friends felt a natural pride in the result of their efforts when they were able to send typewritten letters to their friends. So striking a novelty never failed to achieve effects. One was the admission into the enterprise of Mr. James Densmore, of Meadville, Pa., who was so delighted with the idea that he put money into it before he had even seen the invention. Mr. Densmore had a far-seeing head on his shoulders and he may be said to have rescued the typewriter from a fresh oblivion, for Soule and Glidden abandoned the undertaking. That left Sholes to perfect the machine as far as possible, while Densmore, as a practical man of business, pushed the idea.

But with all his enterprise, Mr. Densmore could not get the machine to market for years. Enlisting, at last, the eloquent persuasiveness of Mr. G. W. N. Yost, he approached the great arms manufacturing house of Remington. This was in 1873. The Remingtons long had their doubts but their instincts were too enterprising to let slip what had some of the aspects of a golden opportunity. Their vast factory and their highly skilled workmen were placed at the disposal of Mr. Densmore and his associates. The Remington Typewriter, under these auspices,

was sent out into the world in 1874. The primitive type of machine resembled its offspring of to-day as essentially as a pterodactyl resembles its descendant, the bat.

Not less marvelous than the ingenuity of this machine, with its countless and exquisite improvements, is the thoroughness with which it has reorganized the industrial life of great nations. Phonography, with its aid, has become as wide an avenue to eminence as the law itself, for the typewriter has made ambitious young men the pupils and the successors of powerful statesmen. It has lifted the women of the Anglo-Saxon race into a realm of opportunity so wide as to affect the destiny of their sex. The position of woman can never be what it was before the appearance of the typewriter, which, as can be shown by statistics, has raised the eligible marriage age of the young girl in England and the United States fully five years. The twentieth century business office is the creation of this machine. So unobtrusively and so insensibly has it attained its present commanding importance that the financial magnate, directing from his headquarters operations involving millions and industrial armies as numerous as Cæsar's legions, has yet to appreciate the potency of the instrument of his dictation. As artillery is the queen of battle, the typewriter is the queen of business.

So prodigious a success invited emulation and the Remington machine, now controlled by the incorporated interests of Messrs. Wyckoff, Seamans, Benedict and their associates, enjoys no monopoly of the field. Many writing machines compete for favor wherever business is transacted. The home itself has been entered, and it may be that this invention will become in time as familiar in the household as is the sewing machine itself.

THE STEAM TURBINE.*

By ARTHUR WARREN.

IT is probable that the last great reciprocating engine-driven power plant has been ordered. Hereafter, the steam turbine will be the prime mover of the new installations.

The layman is apt to think that the turbine may possibly become the steam-engine of the future. As a matter of fact, the turbine is emphatically the engine of the present time. "It is not so young as it looks," said a demonstrator, addressing a meeting of railroad men a little while ago. Its principles are as old as the hills, but modern methods of manufacture have only now made its mechanical construction and its commercial application thoroughly practicable.

Most new things in mechanics come when we are ready for them. If the steam turbine had been perfected one hundred years ago, or fifty years ago, or twenty-five years ago, we would not have been ready for it. If we had had the means to build it, we would not have had the means to apply it in general use. Electricity has given the means for its widest application — the commercial development of electric generating devices. The electrical necessities of the hour have forced ahead the development of the steam turbine. High-powered electrical generators had become so huge that they had almost reached the limits of practical construction and the limits of practical space. And the demand is for higher powers still. Speed and power here are closely related. The big generators were driven as fast as the monster reciprocating engines could drive them. When this point had been reached, the gradually developed turbine was ready. With a turbine revolving at seven hundred and fifty revolutions per minute, it is possible to obtain from a small electrical generator an amount of electrical energy heretofore given only by a machine many times its size.

* From the American Monthly *Review of Reviews*, for June, 1904.

Behind all other forms of steam-engine practice lies the experience of a hundred years. Behind the steam turbine is the practical experience of twenty years. It is in its commercial importance that the steam turbine is new, and this importance dates from yesterday; that is to say, within half a dozen years.

Laymen are averse to technicalities, and this is an article for lay readers. But there are some figures that must be given, and we will begin with these: Energy to the extent of 800,000 horse-power is now daily produced by steam turbines in actual operation in various parts of the world, and turbines aggregating half as much more in horse-power are already contracted for. In the United States alone, one engineering company has turbines to the extent of 250,000 horse-power under order, and another has almost as much, with 50,000 horse-power in daily operation. Each of these concerns builds a different type, and one company, in Milwaukee, builds units as large as 10,000 horse-power. The largest steam turbines yet placed under operation are of about 6,500 horse-power each. But we are only at the beginning. The greatest engine builders are engaging in turbine construction. The signs are everywhere that the day of the reciprocating engine is passing.

What, then, asks the layman, is this new contrivance? Stripped of verbiage, it is a spindle, or rotor, fitted with graduated rings of projecting blades, which, under the impact of steam, cause the spindle to revolve within a close-fitting cylinder, or stator.

Between this seemingly simple proposition and the actual performance of work of high efficiency lies any amount of ingenious theory and engineering skill and long experiment. Any one can force steam into a cylinder and make a paddle wheel revolve, but to make the wheel deliver constant power under varying conditions and at a minimum of cost is a problem upon which many great brains in the engineering world were engaged before it was solved.

Let us borrow from the engineers, for a moment, a few phrases which will give a clear idea of what is done.

A cubic foot of water under 100 pounds initial pressure, and discharging into a 28-inch vacuum, would attain a theoretical velocity of 130.2 feet a second, and would exert 16,900 foot pounds of energy. A cubic foot of steam under like conditions would attain a theoretical velocity of 3,860 feet a second, and

would exert 59,900 foot-pounds of energy. But such steam velocity would require in a turbine an ideal peripheral speed of 2,000 feet a second in order to utilize the power. This would mean 38,100 turns a minute for a wheel one foot in diameter. But this speed is far too great for actual practice. The velocity of the steam must be reduced as it passes through the turbine. This reduction of velocity also deprives the steam of all power of erosion. Thus, the parts are not scored or worn.

Steam enters the turbine through nozzles or stationary guide blades fixed to the inner surface of the cylinder, or stator. This steam is directed upon the spindle, or rotor. The impact upon the spindle blades, combined with the reaction due to the difference in pressure on either side of the ring blades, causes the spindle to revolve. Throughout the turbine these actions are repeated, the pressure of the steam increasing and decreasing as it passes through the alternating rings of blades, gradually lowering to that of the vacuum. This operation may be continuous, as in the Parsons turbine, or divided into stages, as in the Curtis. The low steam velocity not only protects the blades from wear, but the steam thrust on each blade of a Parsons turbine is equal to only about one ounce avoirdupois.

The Hon. Charles A. Parsons, a son of Lord Rosse of telescope fame, introduced the first practicable steam turbine in 1884. It had a 10-horse-power capacity, and was not an economical machine, but it gave a successful demonstration of the principle. At a pressure of 92 pounds of steam, non-condensing, it ran at 18,000 revolutions a minute, and used 35 pounds of steam per horse-power per hour.

Four years later, Mr. Parsons exhibited an improved turbine of 50 horse-power, making 7,000 turns a minute. Soon afterward he had a 200-horse-power turbine giving 4,000 turns a minute, and showing in steam consumption results that compared favorably with good piston engines. Now turbines of the Parsons type work at from 500 to 3,600 revolutions a minute, and they equal the best piston engines in steam economy. But the attention of the world was not much drawn to the new departure until Mr. Parsons built his little steamer *Turbinia,* and ran it at 34½ knots an hour. Then the world wondered. That was in 1897.

The Parsons type of turbine is the best known at present, be-

cause it has been long enough before the engineering world to have secured a wide introduction in many countries. It is a horizontal turbine; that is to say, the spindle, or rotor, is placed in a position horizontal to its bearings, like the propeller shaft of a steamship. In the United States, a turbine of the Parsons type has been built by the Westinghouse Machine Company, of Pittsburg, who have made some improvements in its construction.

A rival of the Parsons turbine is the Curtis, the inventor being Mr. C. G. Curtis, of New York. The Curtis steam turbine is built by the General Electric Company, of Schenectady, N. Y. It is a vertical turbine. A third type is the De Laval, which is made by the De Laval Steam Turbine Company, of New York, and by associated companies of Europe. This is a horizontal turbine, but is very different in construction from the Parsons or the Curtis. It is not built in large units like either of the others, and is seldom constructed in sizes above 300 horse-power. It is a very successful device, many hundreds of the De Laval type being used in the United States, as well as in European countries. The De Laval people have applied the principle of their turbines to cream separators, of which they have half a million at work in the United States.

These three are the turbines best known at this moment in this country. In Europe, the Riedler-Stumpf, the Rateau, and the Zoelly turbines have attracted considerable attention. All these are horizontal, like the Parsons type. There are other types coming forward, and one of the greatest engineering companies in America, the Allis-Chalmers Company, long famous as builders of reciprocating engines, is bringing its skill and experience to the construction of steam turbines, as well as to electrical machinery. The steam turbines which they are building are on lines very similar to the Parsons type, but embodying notable improvements which are the outcome of experience gained in the operation of turbines of various types.

This, however, is not the place to discuss the merits of the respective types of the prime mover which is making so great a change in engine-building, literally, and in more ways than one, revolutionizing that practice both on land and sea. What the layman asks is: "Why is the steam turbine of such great importance? What are its advantages?"

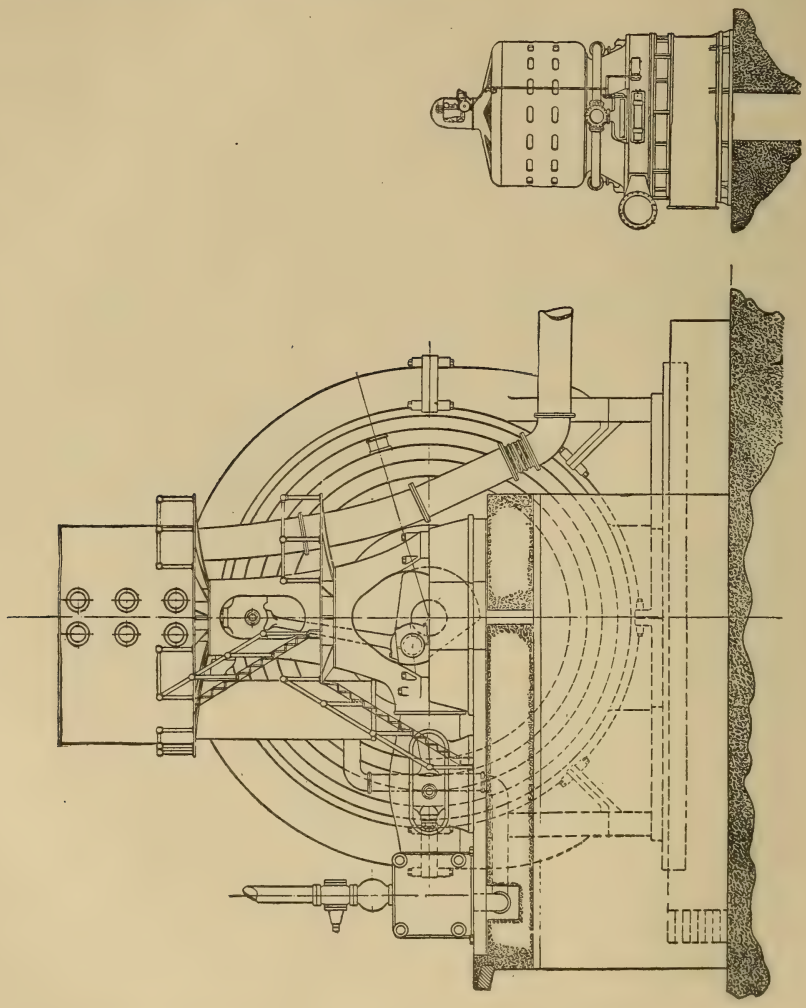
The advantages are many. To begin with, there is the extreme simplicity of construction and operation. Practically, there is nothing to wear out. In piston engines there are many parts that wear. Piston engines decrease in economy with age, but in a turbine there is no such deterioration. The only rubbing parts are the bearings at each end of the spindle. These bearings run in oil, and after years of constant service show literally no wear. Four 100-horse-power turbines have been operating an electric-light plant at Newcastle, England, since 1889, and are still in perfect condition. The oldest turbine-driven plant of the Parsons type in the United States is in Pennsylvania. It consists of four turbines of about 600 horse-power each, driving generators which furnish all the light and power for a large manufactory. These turbines have been in operation four years, and each week one of them runs from twenty-two to twenty-three hours a day, but they have not cost a cent for repairs.

Another advantage of any turbine is the saving in space, whether aboard ship or in a power-house. One type of the horizontal turbine occupies not over 40 per cent. of the floor space required by a horizontal engine of the same power, and not over 80 per cent. of the floor space required by a vertical piston engine of the same power. The space occupied by a battleship engine of the usual stroke and piston speed, figuring on a basis of efficiency of 0.85, is approximately 0.75 cubic feet per indicated horse-power. A turbine for a battleship would require only 0.68 cubic feet per indicated horse-power. Every one can understand the importance of saving space aboard ship. But economy of space is no less important on land, especially in large cities, where land is costly and building construction expensive.

A railway company in Ohio was able to find room for three horizontal steam turbines of 1,000-kilowatt capacity each, with electric generators, switchboards, and transformers, in the space formerly occupied by one 1,000-kilowatt piston engine. A manufactory at Akron, Ohio, had not room enough to add another large piston engine, but a slight rearrangement of its existing engines gave space for the addition of horizontal steam turbines which doubled the power of the plant.

The illustration on this page shows in the most effective way a comparison of the floor, foundation, and head spaces occupied

by one of the newest vertical reciprocating engines, with a 5,000-kilowatt electric generator attached, and a Parsons-type turbine-generator unit of the same capacity. A demonstration of this sort is worth pages of argument.



A Comparative Elevation of a 5,000-Kilowatt Steam Engine Direct-Connected to a Generator, and a 5,000-Kilowatt Curtis Steam Turbine Connected to a Generator, Showing Economy of Space.

Here is a well-authenticated case: a plant was installed containing three vertical cross-compound engines, each driving an electric generator of 1,000-kilowatt capacity. Subsequently, three 1,000-kilowatt units were installed, driven by steam turbines. The turbines saved 900 square feet of engine-room space, and about 38,000 cubic feet. If the entire plant had been equipped with turbo-generators, the saving in space would have been doubled, and the cost of the land, the building, and the foundations would have been reduced by $50,000. In another case, a saving of $2,900 was effected on each 1,000-kilowatt foundation in a power-house by adopting turbo-generators instead of piston-driven.

There is another point which affects the cost of installation, and that is the saving in time, which, of course, is money. The great vertical piston engines are laboriously built up ("erected") in their power-houses, and the multiplicity of parts requires nice adjustment on the site. Steam turbines are sent out from their makers with all the main parts in place and permanently adjusted.

Steam turbines of 600 horse-power have been placed in service in from one to three days after being received. Others have supplied their full load of electric current for commercial purposes within a week, even within five days, from the time they were taken off the freight cars.

There is absolutely no internal lubrication in the turbine. Therefore, the exhaust steam can be condensed into oil-free water, and fed hot directly to the boilers. Superheated steam is used without any injury to the turbine. Superheat of any feasible temperature can be used without reserve. This is not the case with piston engines. Superheat, combined with a high vacuum, gives exceptional economy in the use of the turbine, especially in units of large power.

If water enters the turbine, even in excessive quantities, through the "priming," or foaming, of the boiler, no harm is done. The speed of the rotor may be checked, but that is all. Piston engines have been wrecked by the admission of superfluous water into their cylinders. Wet steam does no injury to the turbine; it merely reduces its capacity. It is axiomatic that piston engines show good economy only when carrying their full load. But the turbine shows the same economy,

within a very few per cent., when running at anywhere from one-quarter of its load to its full capacity. It even carries heavy and continuous overloads without difficulty.

In the matter of foundations, the turbine has another advantage. Foundations for piston engines are expensive; for engines of large power they are very expensive. The turbine needs only a foundation strong enough to bear its weight and keep it in alignment. There are no "thrusts" or vibrations to be absorbed. The piston engine must be bolted down to its foundation. Except on shipboard, the turbine need not be bolted down. It will work in a gallery, or on a wooden floor strong enough to hold it.

Absence of vibration is one of the conspicuous advantages of the steam turbine. One of the favorite diversions of engineers operating turbine-driven power stations is to puzzle visitors by asking them to identify, by touching the stators, those turbines which are in motion and those which are at rest. The average man finds the turbine in motion as free from vibration as the turbine at rest. At all events, this is true of horizontal turbines. Unlike piston engines, the turbines work equally well under constant load, or with great and sudden variations of load. This makes them especially valuable in electric-lighting and power plants. They do not need watching; they take care of themselves.

The applications of the turbines seem to be limitless in possibility. Their special field of service is in motive power for steam vessels, and for driving electric generators whether afloat or ashore. But when that is said practically all is said, for we do nearly everything nowadays by electricity, except the driving of vessels. Even the steam railroads are adopting the newer force. A generation hence the steam locomotive may be as much of a rarity as the horse-car now is,— in any large city except New York.

It has been said that the steam turbine is the engine of to-day. Already it is world-wide in its application. It is working at the De Beers mines in Africa to the extent of 2,000 kilowatts. It is driving passenger vessels on the Clyde and the English Channel. The Allan Line is building a large turbine steamer for the mail service between Great Britain and Canada. The two new 25-knot Cunarders are to be turbine driven. There

will be 60,000 horse-power in each ship. The highest-powered steamship ever built heretofore is the *Kaiser Wilhelm II.*, of the North German Lloyd. This vessel has reciprocating engines of 40,000 horse-power. The significance of the Cunard departure must be apparent to every one. And the comfort of ocean travelers will be vastly increased by the absence of the vibrations caused by piston engines. The newest ocean-going steam yachts are turbine-driven. Turbine torpedo-boats are no longer novelties. The great naval powers are still experimenting, but merchant shipowners have gone far beyond experiment, and manufacturers in all countries are installing turbines as fast as they can get them.

In London, the Underground Electric Railway Company has ordered 60,000 horse-power in eight turbines; the Metropolitan Railway, 14,000 horse-power. The city of Liverpool has ordered 4,000 horse-power in turbines; and Brighton, 7,500 horse-power. One company, near Glasgow, is putting down turbines to the extent of 16,000 horse-power; another, in Yorkshire, 6,000; and the town council of Harrogate, 1,000, for lighting their attractive town. Turbines to the extent of 4,000 horse-power are ordered for supplying the electric current to tram lines near London. Nearly all of these turbines are horizontal, of Parsons or modified Parsons type. In Chicago, the Commonwealth Electric Company has been using a big Curtis turbine since October 2, 1903. This turbine is rated at 5,000-kilowatt capacity,— about 6,700 horse-power,— making 500 revolutions per minute, at a usual pressure of 185 pounds. Two other turbines of the same make and capacity have also been installed, and the station is so planned that it can eventually contain fourteen turbine units, vertical or horizontal, of whatever type may be chosen. Paper mills, textile mills, and machine shops in the United States are being successfully operated by steam turbines, and electric railways are ordering them for their power-houses. The New York subway will be lighted by electricity generated by horizontal turbine-driven dynamos.

There are many records of turbine performance which those who run may read. Before me is the record of a turbine in Silesia, which ran without stopping (except for a few hours every three or four weeks, when the boilers were cleaned) from October 4, 1901, to January 17, 1903. The only repair needed was

in a valve which had been cut by acid-bearing feed-water. The lubricating oil was changed only once in twelve months, and only eighty-five gallons were used in a year. A 5,000-horse-power turbine, at Frankfort-on-the-Main, ran a year without any necessity for repair. At the Municipal Electric Supply Station, at Elberfeld, a 1,000-kilowatt turbine, under full load with normal conditions, gave the following results: superheat 26°; steam pressure, 141 pounds; steam used for electrical horse-power, 14.4 pounds. This is equivalent to about 12.3 pounds per *indicated* horse-power. Turbine performance is measured by brake horse-power, or electrical horse-power, not by indicated horse-power. It is claimed that this is fairer to the purchaser, because engine friction and other variable conditions often vitiate the value of tests that are calculated in piston-engine ratings. Brake horse-power is the power actually delivered.

An American-built turbine, driving a manufacturing plant operated by electric motors, has carried 33 per cent. overload regularly without any perceptible harm. Before the American Society of Mechanical Engineers, last August, an account was given of a turbo-generator in Connecticut. Measuring the power as delivered at the pulleys of the motors, it was found that piston engines in the same shops required three times as much coal as the turbine to give the same power.

New as the layman thinks the turbine, the fact remains that it is a very ancient device. Hero, of Alexandria, described a reaction turbine as far back as the year 120 B. C. It was a spherical vessel mounted on trunnions through which steam was admitted, the exhaust issuing from openings tangental to the sphere. Giovanni Branca, of Italy, invented the impact turbine in 1629. But these were curiosities rather than efficient machines, judged by the requirements of the present day. It was only when the electrical age had got fairly started that the necessity for the turbine made itself apparent. And it was only then that we learned how to handle the material, how to make the tools to fashion it, and how to overcome the difficulties of the enormously high speeds of which this rotary prime mover is capable.

Perhaps no fact in all the record is more significant than this: that the greatest engine-builders in the world, a company whose mighty reciprocating engines are everywhere regarded as among

the marvels of the industrial world, have built at Milwaukee an immense manufactory for the production of the rotary prime movers, which are destined to drive the reciprocating engine into retirement. Nor is this all. For the same company, by the same reason, enters the electrical field. The builder of steam turbines must build electric generators. This is the newest phase of the tendency of the times. For the turbine and the dynamo are henceforth practically inseparable.

THE EVOLUTION OF THE AUTOMOBILE.

By CHARLES WELSH.

WHEN that famous old fraud Mother Shipton prophesied in the time of Henry VIII. that "Carriages without horses shall go," she was only prophesying after the event, for sails, windmills, and springs, had been employed as means of power locomotion on common roads early in the sixteenth century. These early inventions it is true were rude, clumsy, and imperfect. Johann Hausted, of Nuremberg, for example, made a chariot about this time which was propelled by springs. It was capable of a speed of one and a quarter miles an hour! A veritable Nuremberg toy, alongside of our modern machines with a record of 75 miles an hour.

But far sighted men had believed in the possibility of automobility for hundreds of years. The automobile was foreshadowed by Roger Bacon in the thirteenth century, for he wrote, "We will be able to propel carriages with incredible speed without the assistance of any animal."

If we take a hasty glance along the stream of Time, noting by the way what the last four hundred years have brought forth in the shape of self-propelled carriages, we shall remark that the great Newton suggested propulsion by the reaction of a steam jet in 1680, and that Father Verbiest, a Jesuit missionary to China, actually constructed a machine so propelled in 1665. The celebrated engineer, Pupin, built a model for a road carriage to be propelled by an engine with a cylinder and piston, and as soon as steam began to come into practical use the idea of self-propelled vehicles become very general, and many busy brains set to work on the problem.

The great Frenchman, Cugnot, who constructed the earliest practicable power locomotives for road use during the years 1763-1771, may almost be called the father of automobilism. His first carriage was designed to transport cannon. His second

steam carriage, built in 1770, is still preserved in Paris at the Conservatoire des Arts et des Meltiers. "The ideas of Cugnot," says the Marquis de Chasseloup-Loubat, "were an entire century in advance of the mechanical means by which they could be realized."

The attempt led to no satisfactory results. Everything was defective — motive power, steering, control. Nevertheless the carriage ran, and ran so well that it broke down the enclosure of the ground on which it was tried. It is an incontestable fact that Cugnot is the inventor of automobile locomotion, and that the honor of first having imagined and realized a new method of transport, estimated to play an important part in the welfare of many lands, belongs to him.

F. Moore in London, 1769, and Livingston, in 1784, were well-known makers of steam carriages of a kind, as were also Oliver Evans and Nathan Read in this country, who made some serviceable machines.

It was the idea of the automobile that led to the invention of the steamboat. Late in the eighteenth century John Fitch, of Hartford, Conn., conceived the idea of a steam carriage. It occurred to him to construct it so that it could cross a river, and this led him to build the first steamboat, which he ran on the Connecticut River. The first horseless steam fire engine was devised by Frank Curtis, of Newburyport, Mass., shortly after 1860, and it ran successfully under its own steam. In 1867 Mr. Curtis built a steam carriage with a speed of 25 miles an hour, and it ran for eleven years.

But to return to our chronological order, there is one machine made by Wm. Murdock, in England, about 1784, which is still in good working order, and the celebrated Cornish engineer, Trevithick, began to build road engines in 1803. The first compressed-air auto-car was made about 1810. "It was in England towards the third decade of the nineteenth century," says the authority before quoted, "that we saw the idea of Cugnot reappear. The same impulse which moved English engineers to build railroads in order to free the great industrial centers from the economic tyranny of those who constructed canals urged them to study methods of automobile locomotion on highways. That is to say, in its inception automobile locomotion was considered as an auxiliary to the railroad, which it really is.

"Unfortunately the promoters of the railway lines did not at all understand the respective spheres of action of the machine on the rail and the machine on the road. They took umbrage at automobile locomotion, and since they had much capital and influence at their disposal, they secured a law from the English Parliament which effectually killed automobile locomotion. It ordained among other things that a man carrying a red flag by day, or a red lantern by night, must be kept a hundred yards in advance of every automobile vehicle."

Until about 1840 steam was a common motive power for road-vehicles. The road engine them, as the bicycle and automobile to-day, led to great improvements in road building in England and on the Continent of Europe. The famous MacAdam, Telford and Neill, men whose names are indissolubly connected with the best modern road-making, flourished at about this time. But British ingenuity never succeeded in making the light and easy running machines which the Frenchmen and the Americans achieved in these later years.

With the coming of the railroad, the road-engine was practically doomed for the time, although in reality the former was the outcome of the craze for the latter.

The vested interests in the railroad, as we have seen, soon became so enormous that legislation was directed to the restriction of the road-engines, and they were employed under all sorts of crippling rules and regulations besides these referred to, until they practically disappeared, and their more powerful and swifter rival held the field alone for steam transportation for men and merchandise until the modern revival, which may be said to have had its origin in about 1878 when Leon Bollee, a French engineer, established his auto-car which weighed three and a half tons. Compare this with the modern Daimler petroleum motor which weighs but one ton and will do twice as much work. In 1886 Count Albert de Dion in his steam automobile showed what was the first practical horseless carriage of the modern type. Another Frenchman, Serpollet, was among the beginners of the modern perfect steam auto-car, and from Germany came the first oil motor — the Bentz.

A great step in the popularization of the auto-car was made in the early nineties, when the owners of *Le Petit Journal* of Paris organized a race between the various makers which attracted

world-wide attention, and in 1898, when the Exhibition was held in Paris under the auspices of the Automobile Club of France, at which one thousand one hundred vehicles were shown and thirty thousand spectators were present.

A great impulse to the development and use of the automobile in England was given by the withdrawal in 1897 of many of the laws which had hitherto hampered and restricted them. Meanwhile our own inventors and manufacturers were not idle, and they soon set about working out the possibilities of the machine and developing it, until to-day the American automobile, if it does not lead the world, is at least abreast of those of the pioneer countries of Europe. In June 1896 an automobile contest, organized by the proprietor of the *Cosmopolitan Magazine,* was made in New York from the City Hall to Tarrytown on the Hudson and return. And this seems to have given a remarkable and powerful impulse to automobile industry in this country. It attracted attention all over the country. The winner was the Duryea gasoline motor wagon.

It was these and other contests which brought about the formation of the American Automobile Club with its headquarters in New York — which has now a large and increasing membership roll. They have already co-operated with the League of American Wheelmen in their good work on behalf of good roads. It is said that in the summer of 1898 there were not thirty automobiles in the United States, but by August, 1899, at least eighty companies had been organized with an aggregate capital of nearly $400,000,000. Two years later over 300 firms were making automobiles, while to-day these figures may fairly be doubled, although there are no reliable statistics available.

The patent office records furnish a sure indication of the directions in which the minds of our vast army of inventors are running — and of the interest taken in any given industry. No less than 275 patents dealing with automobiles in some shape or another were recorded during the last ten years of the nineteenth century and the annual average since then has been considerably larger.

This enormous industry has naturally led to the establishment of important periodicals devoted to its interests all over the country,— East and West, North and South. About twenty such periodicals are extant to-day, and the magnitude of the industry

is reflected in the most striking manner by the immense advertising patronage which they enjoy. Automobile literature in Europe is as extensive. The number of books devoted to the subject, the attention it receives in the magazines and the number of new automobile journals which spring up every week is too great even to be chronicled here. But it is not necessary to go to the trade journals to see this. It is scarcely possible to take up a magazine or a newspaper to-day without being reminded of the presence of this new industry, and the streets of every great city, and every highway in the United States, give evidence that this great adjunct to, and developer of, commerce, has come to stay.

We have referred to the effect of the automobile and the cycle on the development of good roads, and have given some idea of the enormous industries to which it has given rise, furnishing employment to hundreds of thousands throughout the country. But this new means of locomotion is doing more than this. As men "run to and fro knowledge is increased," new tracts of country are opened up not only for the traveler for pleasure, but for profitable purposes as well. The chief interest in the automobile has hitherto been in its usefulness for the transporation of man. It is now receiving considerable attention as affording increased facilities for the transportation of merchandise, and it may be the means for sending a great proportion of the dwellers in crowded cities back to the land. With increased facilities of cross-country transportation there comes the possibility of that *petite culture,* in which "every rood of land maintains its man," such as is found *par excellence* among the prosperous and contented peasantry of Belgium. Of course we must have our agriculture on the grand scale in the West, but around and about our Eastern cities there are countless acres of land which might be turned to profitable use, if only there were cheap and easy methods of bringing their produce to market, and the automobile may be the means of accomplishing this.

Indeed, it has already done so in England and in Europe. The use of motors for farm and market work is capable of enormous development. But there is no limit to their employment. The War Department, the Postoffice, the doctor, the commercial traveler — all must use the automobile in the time to come, and as has been well said, "the revolution worked by railways is a

small thing compared with the revolution now being produced by the motor-car."

We have seen that there are three great periods in the evolution of the automobile — first, the long period of its inception before the invention of railroads, and its partial development in the earlier decades of the nineteenth century. Then the period of abeyance, when it was eclipsed, if not driven out of existence, by the railroad power, and last, the great modern revival of the past twenty-five years.

Electricity, steam and gasoline or naphtha, are the three main sources of power that do the bidding of the man behind the lever. Other sources of power, such as compressed air, liquid air, carbonic acid gas and alcohol, have been experimented with, but are regarded as impracticable by expert authorities. In large cities, the electric vehicle was the first to come extensively into favor. It is especially adapted for all city uses, for it is without odor or vibration, and is almost noiseless; but so long as it is obliged to depend upon a storage battery it must be very heavy and can run but a limited distance — about 25 miles — without recharging. Therefore the automobiles run by steam or gasoline are superior for long distance purposes.

It is not within the province of this paper to enter into technical mechanical details of the evolution of the automobile. Increased power combined with diminished weight, higher speed with smooth-running, accurate and simple steering gear, perfect lubrication and absolute control, are the directions in which it is being evolved before our eyes, and it is in these directions that manufacturers have been moving during the past twenty-five years. Every day sees some superfluous part removed, some simplification introduced. Every month or so these modifications bring about a reduction of cost both of the machine itself and in its maintenance. Every day also sees some new adaptation of it to commercial purposes.

The evolution of the form and shape of the automobile is one of the most interesting features of its development. The first railroad carriages were just the ordinary coach on flanged wheels to keep them on the track. The adaptation to conditions gradually brought about our magnificent hotels on wheels, in the shape of parlor, dining and sleeping cars. So the first motor carriages were built on the plan of the ordinary horse carriage, but every

day sees a departure from that form and a development more in accordance with the conditions. What the ultimate type will be it is difficult to forecast, but it will doubtless develop into a bluntly pointed front — a tendency, perhaps, to cigar shape — and a much lower body, probably within a step of the ground.

As we have indicated, the cost of automobiles is in a state of constant change. From the catalogues of the leading manufacturers issued in 1904, it appears that an electric speed road wagon of one of the leading types can be bought for $850 fully equipped, and larger and more expensive types up to $2,000. These carriages are started as easily as turning on an electric light. The brakes are simple and easily handled and the hitching strap is done away with by the fact that all that is necessary to secure your finding the vehicle where you left it is to take out the starting plug and put it in your pocket. Goods delivery wagons of the same motive power, and with the same general equipment, cost from $1,400 upward according to size and carrying capacity. An electric carriage for family use costs about $2,000, and an omnibus from $3,000 to $4,000.

The prices of gasoline vehicles range from $1,000 for a first-class road carriage to $4,000 for an omnibus. The cost of running may vary from 50 cents to $1.00 and more per hundred miles, according to the size of the machine.

The driver of gasoline vehicles must know something of the principle of the machine, and is often called upon to apply his knowledge. But he can go anywhere — up hill and down over the worst roads through mud and snow and can go at any rate he chooses. He can buy his fuel in any village street and in every city, and is not dependent upon electric charging stations. Therefore, as we have said, for touring purposes the gasoline vehicle has great advantages over that propelled by electricity.

Steam has been more generally applied to the heavier classes of vehicles, though some pretty lighter ones have been made, chiefly in this country. They are easily started and easily stopped and fuel and water can be obtained anywhere; but they have obvious disadvantages and have not come into general use for passenger purposes.

Records, like "promises and pie-crust," are, as we all know, made to be broken, and almost every day sees the old ones shattered and new ones made. A speed of seventy-five miles an hour,

attained on an ordinary road in France, and a 3,000 mile trip lasting fifteen days and two hours in this country were two of the records for 1904.

A last word on the evolution of the automobile should be on the subject of the evolution of public opinion with regard to it. When the bicycle was becoming popular the prejudice against it from pedestrians and drivers was unbounded, and the automobile has been even more severely attacked, perhaps not altogether without reason. But as the driver of the automobile becomes more expert and the public becomes more accustomed to them, these prejudices will die out. Horses are being educated to meet motors without shying, as they were educated to meet railroad trains, trolley cars and bicycles, and familiarity is daily breeding — not contempt, but the necessary added care on the part of all concerned, which this new method of locomotion calls for.

AN ELECTRICAL STORM INDICATOR.

By EUGENE P. LYLE, Jr.

A STORM raging somewhere a hundred miles away calls a man up by telephone and tells him in plain storm-language what it is doing and where it is going — that is one of the recent astounding achievements in electrical science. Benjamin Franklin, it is true, brought the storm down to him via a kite-string, but Franklin and the storm had to come together if they wished to communicate. The wireless telephone, however, has now changed all this.

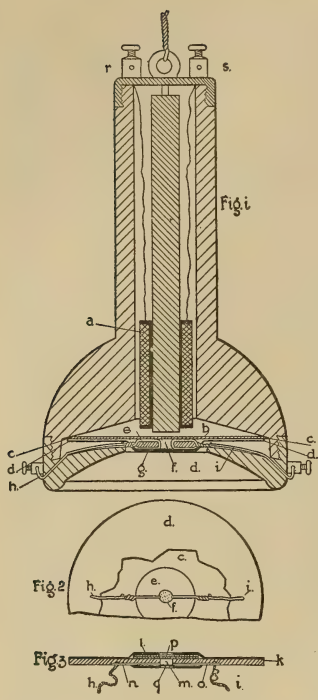
In his laboratory at Intra, in Italy, Dr. Thomas Tommasina has one telephone on his desk and another in his living apartments, and no storms can knock at his door without being heard.

Dr. Tommasina's telephone is, to all appearances, like any other, but in its internal arrangement there is an important difference. When he hears some one call him up on the telephone, the sturdy inventor answers by putting his ear to the receiver and listening. Then he announces in a matter-of-fact way to those who may be present that a storm is coming. The visitor is skeptical. Outdoors all is clear and serene. There are none of the little menacing gusts of wind, nor the dread, sultry quiet. Dr. Tommasina nevertheless declares that he cannot be mistaken, for has he not just received a telephone message from the storm itself? When before long the storm is seen to approach, the visitor is amazed and wants to know more about this new telephonic contrivance.

It all began with metal filings. First the inventor came upon a curious phenomenon not before known to him; namely, that the tiny grains of metal filings have the property of adhering to each other under the action of an electric current. He had constructed a very elementary sort of an electro-magnet which he called by its French technical name, *cohéreur*. This appa-

ratus, for detailed explanation of which see Figs. 1, 2, and 3, was contrived as follows. A little pendulum of copper and zinc, nickled over, with a ball one centimeter in diameter (.394 inches), was suspended from a support by a very fine wire and connected with one of the poles of a battery. A fraction of an inch below the pendulum ball a copper disk about an inch in diameter was welded to an elastic copper stem and connected with the other pole of the battery. The disk was horizontal, and the pendulum was perpendicular to the center of the disk. The electric circuit was connected with a second circuit that included a small incandescent lamp, and this second circuit could be cut out at will. The experimenter laid a pinch of nickel filings on the disk and lowered the pendulum till it barely touched the filings. Then, turning on the current, he slowly lowered the disk a very little, and made his first discovery in the series, observing that a delicate, shining thread was clinging between the pendulum ball and the disk. Under the magnifying glass the shining thread proved to be made of tiny grains of the nickel filings, hanging one to another, and forming a flexible chain through which the current passed. He knew the current was passing, because the incandescent lamp was still lighted. Being very careful not to jar the contrivance, he managed to make these little chains almost two-thirds of an inch in length, one at a time. If a chain broke at its base, the top section would hang to the pendulum for an appreciable time, although the lamp had gone out and the current was interrupted. When this happened, if the end of the hanging chain, by lowering the pendulum, were made to touch the top of the little heap of filings on the disk below, the circuit would close again, the incandescent lamp would be relighted, and a new chain made by gently drawing up the pendulum. This, briefly, is the electro-magnet, or *cohéreur,* which was to become the key to the invention of the storm prophet.

When Dr. Tommasina wearied of experimenting with filings, and among other things tried carbon on his magnet, he was on the direct road to his wireless storm telephone. His substitute for the metal filings was carbon powder, which he procured by grinding up an arc-light carbon and sifting the result so as to get the average-sized grains. Putting a pinch of the grains on the copper disk, after many trials he was able to produce



OUTLINE OF THE TOMMASINA TELEPHONE, SHOWING CARBON MAGNET.

a, Electro Magnet. b, Iron Membrane. c and d, Insulating Covers. e, Insulating Plaque of Magnet. f, Cavity for Filings of Magnet. g, Mica Covering. h and i, Electrodes of the Magnet. k, Insulating Membrane. l, Iron Plaque. m, Filings or Carbon Powder. n and o, Silver Sheets. p and q, Mica Sheets. r and s, Poles.

chains twelve to fifteen mm. long (.47 to .59 inch). Having satisfied himself that the carbon grains would hang together by the help of an electric current, the inventor proceeded to make more magnets, or *cohéreurs,* until he succeeded finally in getting a carbon instrument as sensitive as the one with metal filings; the carbon grains, moreover, having the very important advantage of instantly becoming demagnetized and falling apart when the current is turned off, and as quickly reforming into chains when the current is turned on again.

We have already noted that the filings in becoming demagnetized still cling together for several seconds. Dr. Tommasina next placed his carbon *cohéreur* vertically, and plunged the two short wires of its electrodes into cups of mercury in order to avoid jars, and with this arrangement he rendered the apparatus so sensitive that it sufficed merely to stop the current for the carbon to lose all conductibility, and that without any jarring whatever.

It was now necessary to have another *cohéreur,* also of carbon, and practically the same as the one soon to be applied to the storm telephone. It consisted simply of two arc-light carbons inserted in a glass tube, which, when finally adjusted, proved to be an instrument of extreme sensitiveness. Seeing what he could do with non-metallic conductors, the inquisitive scientist wished to determine whether the human body could become the seat of extra currents inducted by electric vibrations, and placed

himself in the circuit with his *cohéreur* and demonstrated his hypothesis. Although this proved to be only a side line of investigation, as far as the storm prophet is concerned, Dr. Tommasina was, however, nearing the goal, for he succeeded in obtaining the self-demagnetization, or *auto-décohération,* of his carbon magnet (a peculiar property of carbon powder, which he believes he was the first to discover). By applying this discovery to the telephone he now found a means to receive telephone signaling without the aid of wires. By automatic demagnetization is meant the immediate disappearing of coherence between the carbon grains after each electric wave, and that without any shock or jar or stopping of the current being needed.

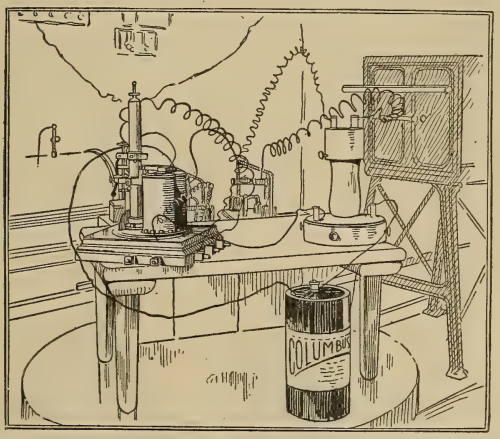


Fig 4. Arrangement for Operating Dr. Tommasina's Telephone.

Dr. Tommasina was, however, not yet satisfied with this discovery (brought about by means of a glass tube *cohéreur* of arc-light carbons), for the automatic phase was still very irregular, and often a shock or the interruption of the current was needed to make the grains demagnetize. Finally he blamed the inertia of the relays for his poor success, and, with the second battery, simply cut them out of the circuit and went on with his experimenting. In their place he inserted a telephone receiver, but though no shock was now ever required to make the grains shake loose of one another, yet sometimes the magnetism would not pass away quick enough.

The inventor now began to work on still another *cohéreur* which he could put into the case of the telephone receiver itself. From a sheet of ebonite about .1 inch thick he cut out a rectangle 12mm. by 15mm. (.4728 inch by .59 inch), bored a hole .7 inch in diameter in the center, and down the middle of each face filed a notch parallel with the longest side of the rectangle. He then passed a silk-covered German-silver wire through the hole, and along the notch on either side, and twisted the two ends together (see the small cut in Fig. 6), then attached a second wire in the same way, opposite the first. Both wires had been bored and polished at the place where they passed through the hole. The hole was then almost completely filled with well-dried carbon powder and plugged up with a sheet of mica cemented over it on each face of the ebonite. This, then, was the new electro-magnet, or *cohéreur*. Its electrodes were simply the two wires, about .04 of an inch apart, brought in contact with the powdered carbon. An examination of Fig. 6 will make the explanation clear.

Following out his idea, Dr. Tommasina unscrewed the cover of a telephone receiver, cut the wires of the electro-magnet

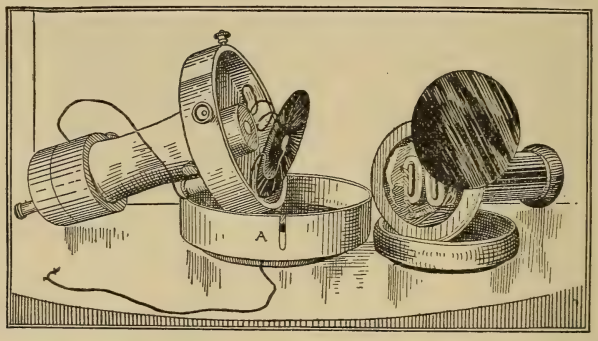


Fig. 5. Telephone with Dr. Tommasina's Magnet of Carbon Powder.

inside, and inserted his new *cohéreur* so as not to touch the vibrating membrane. This arrangement worked to perfection with one cell of a dry battery and proved to have a sensitiveness equal, if not superior, to the best metal-filing receivers. The cavity of the *cohéreur* being almost filled with powdered carbon, the receiver operated in all positions. By putting the

ear to the telephone one could hear a clear, clean-cut shock with each electric wave, no matter how great the rapidity. With carbon powder thus substituted for filings, there resulted not only the advantage of automatic demagnetization, but a most satisfactory regularity, even with strong currents. The inventor explains that every microphone is but a magnet-demagnetizer (*cohéreur auto-décohéreur*), whose sensitiveness increases inversely as its size and the quantity of powder it contains. Instead of carbon powder, filings may be put between the carbon disks and the spoken words are reproduced in the receiver just the same. Either *cohéreur,* applied to a vibrating membrane, constitutes a microphone. Dr. Tommasina hopes that he will be able to register telegraph messages by inserting a Morse apparatus in the circuit of the *cohéreur,* and solve the problem of rapid transmission by means of the Hertzian waves.

Dr. Tommasina calls his altered telephone an electro-radiophone, because it has the property of signaling the radiations produced by electric discharges of near or distant storms by means of transforming such radiations into sounds. Several physicists had already made instruments which would register atmospheric discharges automatically, as with tubes of metal filings. They are, in fact, registering barometers or electro-radiographs. Professor Boggio Lera, another Italian scientist, constructed an apparatus that would trace little lines, like arrow-shafts, to indicate the intensity of distant atmospheric discharges. Dr. Tommasina's method, however, is much more vivid. His observations at Intra, Italy, have convinced him of its utility. The instrument is practically that already described, the carbon *cohéreur auto-décohéreur* in a telephone receiver. There is no metal contact whatever. The electrodes are two little arc-light carbons adjusted so as to touch lightly in a glass tube, and between them are placed little grains of the same carbon. These latter have been separated from their own dust, and they and the electrodes have been thoroughly dried in a flame. The *cohéreur* is fixed vertically in a tube of the telephone horn and inserted in the circuit of the electro-magnet. Thus, when the receiver is to the ear, the *cohéreur* is horizontal, and the grains have an equal pressure on each electrode. Because carbon is so porous, the glass tube had to be hermetically sealed to protect it from all traces of humidity.

His laboratory being some seven yards from the ground, Dr. Tommasina ran three copper wires through a crack in the glass of his window and spread them outside like a fan, whence they stretched to a platform. This platform was covered, but open to the weather on all sides. The wires terminated in rubber tubes, and were fixed to glass insulators covered inside and out with paraffine. These insulators were twelve yards from the ground and two yards apart. The wires were thirty yards long. In the laboratory the ground connection was made by a conductor of water. When a storm should come too near for safety, all the connections could be easily removed.

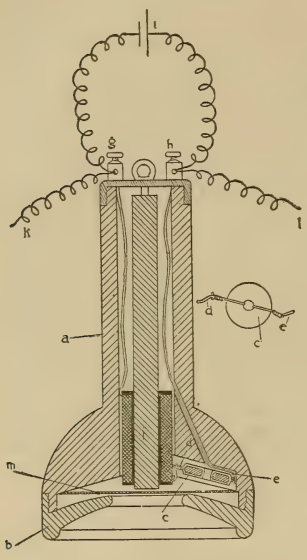


Fig 6. a, Case of Receiver. b, Cover of Receiver. c, Electro-radiophone. d and e, German-silver Wire. f, Electro-magnet. g and h, Wire Connections. i, Little Dry Battery. k, Receiving Wire. l, Ground Wire. m, Telephone Membrane.

Dr. Tommasina describes one occasion when his storm prophet was more entertaining than usual. Till noon of a September day the weather had been a model of calm beauty, but, nevertheless, the radiophone had been making varied noises, with very clear shocks, ever since morning. There were certainly some atmospheric discharges at a great distance. Towards two o'clock the telephone bell rang, and in the telephone the noises grew more and more energetic. Sometimes they resembled the prolonged rolling of thunder, but these came from many discharges, extremely rapid and of varying intensity. Soon the bell rang more frequently, and by half-past three it was jangling incessantly, and he cut it out of the circuit. But now distant lightning could be seen on the horizon, and large clouds began to form here and there, though as yet no thunder was audible to the naked ear. The noises in the telephone had steadily grown more intense, and then of a sudden they changed to a compact crackling, steady in volume and continuous. Several seconds later rain

began to fall, and simultaneously the first thunder clap made itself heard most energetically. The inventor had no sooner removed the connections of his apparatus than torrents of water flooded the streets, and the darting lightning struck the ground in several places nearby. When the storm had passed over, Dr. Tommasina reëstablished his connections, and listened to the last distant discharges, even to their disappearing altogether.

When the weather changes without bringing on a storm, the peculiar crackling already mentioned foretells it faithfully, even twelve hours before rainfall. Thus, because of its great sensitiveness, the electro-radiophone may some day be invaluable on shipboard for discovering and locating distant storms, for following their course, and as a warning to get out of their way.

WHEN EARTHQUAKES WRITE THEIR AUTOGRAPHS.

By LUDLOW BROWNELL.

THE world's earthquake headquarters are at Shide, Isle of Wight, and, oddly enough, in a stable. But though humble the building be, every able quake of the ten thousand a year has to report there promptly and have its picture taken. The owner of the stable insists on this. He is John Milne, a Fellow of the Royal Society, who for twenty years was Professor of Geology and of Mining in the Imperial University in Tokio, Japan.

Every earthquake of any pretensions at all, whether in Japan, Alaska, Kamchatka, or at the bottom of the deepest sea (where, indeed, most quakes originate), sends its signature through the earth direct to Professor Milne's stable. Then, to make sure, it sends out "repeats" rippling along the earth's surface east and west. These repeats reach the stable, in due course, from opposite directions and establish the genuineness of the through message.

But quite as unique as his stable will be Professor Milne's new earthquake observatory. Here instruments will be constantly on the watch, and will report to him if the earth's crust humps itself up so much as an inch five hundred miles away. So delicate are these Milne pendulums that the pressure of the dew on the ground outside of the observatories, and even light and shade, affect them. They bend towards a shadow, swinging in the direction of that side of the building which is the damper and therefore the heavier, while the sunny side, being the drier, exerts less pressure and does not tip things so much.

Little bendings are in progress all the time. The "immovable" hills are bowing and scraping to each other constantly.

Every evening, as the dew settles in the valleys between them, they nod one to another. So, likewise, do the mountains, even to a greater extent. Gravity is tugging all the time. And in London, too, where earthquake sensations are practically unknown, the earth bends daily, and the buildings, like the hills and the mountains, nod to their friends opposite when the morning traffic begins. On Sunday, usually, their manners take a rest, excepting in such places as Petticoat Lane, where business flourishes in as lively a fashion as in Paris. Heine said that even the trees made obeisance to Napoleon the First when he entered Berlin. This was imaginative, yet truthful, for the weight of the crowd along Unter den Linden made a tilting sufficient for Professor Milne's pendulums to have recorded distinctly. One might say the crust of the earth acts like a steel spring, it bends so easily.

Faults, as geologists call certain breaks in strata, show where great pressure has made the spring give way. Ten years ago such a fault occurred in the central part of Japan, ruining large areas of cultivated land and destroying close upon ten thousand lives. This disaster cost the Mikado's government £3,000,000. The old chalk cliffs at the Isle of Wight show many such faults. The stratum on which the professor's stable stands crumpled up during that process of slow compression which formed the Alps. His instruments are independent, and rest on blocks of stone that go down into the chalk without touching the buildings round them.

All the earthquake signatures from the various parts of the earth come through this chalk — not an ideal material for transmitting, one would think, but the professor works with it very well. These signatures are in great variety, and make interesting reading, for they show character and tell much about themselves and their conditions. The professor, of course, is an expert in their chirography. The number of the small letters in the signatures, for instance, which, as earthquakes write, are always at the beginning, tells him how far the quake has traveled, while the large letters, like old-fashioned "S's," tell of the intensity. As he knows all the "centers" of first-rate importance — that is, the places where the great earthquake troubles originate — he can guess, with considerable likelihood of being right, which center sent the message.

For instance, there is the Tuscarora Deep, which has sent so many fearful tidal waves against Japan's east coast; another, off the coast of Ecuador, which has done great damage in its time, and has sent great waves eight thousand miles across the Pacific; another in the Bay of Bengal; still another, newly found near the Isle of Guam, the deepest bottom known; one, also, in the mid-Atlantic not far north of the equator, which made so much trouble for Charleston, S. C., U. S. A.; and one somewhere off the coast of Alaska. Any one of these is fairly suspicious, for it is ready to act whenever opportunity occurs.

The instruments, which the professor has ready in his stable for automatic attachment to all able earthquakes, are rather simpler in appearance than one would expect, considering the work they do. They are the result of a score of years' experimenting. The pen-points that do the writing are fine hairs of glass on the ends of pendulums which the professor has arranged to swing horizontally. In the stable is a seismograph, as he calls it, which writes on a long strip of paper covered with lamp-black, and in the carriage house a camera, always ready to photograph a quake. To obtain a truthful negative depends on the pendulum. A ray of light is reflected from the end of the pendulum, and records automatically on a roll of sensitized paper which runs over a pulley turned by clockwork. When there is a quake the pendulum swings, the ray of light moves back and forth, and there is a photograph — something that resembles a picture of a distaff of the days of spinning-wheels.

In the new building, which is just beginning work, the principal object, as regards size, is a lamp-post, one that the professor picked up at a bargain, and put to a purpose hardly contemplated by the man who made it. This post stands over in the corner on the same side as the entrance, and serves as the upright for the pendulums. One of the pendulums points south and the other west. They have heavy weights at the end to insure steadiness, and glass pens for jotting down their earthquake impressions of Borneo, Japan, Alaska, and other places. The pendulum pointing south writes with an arm that runs along parallel to the other pendulum. In this way Professor Milne obtains two signatures side by side on the revolving cylinder he uses for receiving records.

There is a dark room in here, as well as one in the stable,

for general photographic work. Besides, there are two stone columns running down into the chalk and free of all connection with the house. These the professor will use for those instruments that need to be isolated from ordinary vibrations.

With the instruments in his stable the professor has shown the earth to be a strangely restless body, shivering all over every thirty seconds, and heaving up its crust over thousands of square miles of surface at a time in stupendous sighs once in seven days, taking, as it were, a Sunday afternoon nap.

He has also located many of the centers from which earthquakes emanate, and has shown that ninety per cent. of the shocks in 1899, for example, originated at great depths beneath the sea. If the knowledge he has accumulated in his studies of earth vibrations, quivers, shakes, and undulations had been at hand when the cable companies laid out their routes they could have saved £800,000 by avoiding the danger places Professor Milne has marked on his charts. It is safe, too, to say that engineers would have built hundreds of railways and bridges differently if they had had the benefit of the latest researches in earthquake construction.

In shaky countries like Japan it would be difficult to overestimate the value of Professor Milne's deductions. The Japanese Government appreciates this, for it long since established a chair of seismology in the Imperial University, and has put up some nine hundred stations for observing its superabundant tremors, and the Mikado has decorated the professor with an order of particular merit, making him "Chokunin." The government is now at work on a seismic survey of the empire, and will publish as soon as possible a map, colored variously according to quakiness, dark for the most unsteady parts, and light for the parts that quake least. Other earthquake countries will follow Japan's example; thus has the Land of the Rising Sun, though the youngest of the Powers, begun already to teach her teachers.

Japan is rather responsible for seismology anyway. If she had not engaged Professor Milne to teach her geology and mining, he might have spent his days on firmer terra, so to speak, and never have investigated earthquakes, nor invented seismographs for them to write with, nor seismo-cameras to take their photographs.

So it is that in Shide, up by the golf course just on the western edge of Newport, where even the railways with the mails are not too certain, there is a man who can tell you of an earthquake at the antipodes a few minutes after it has happened, and, what is more, has taught others, in many parts of the world, to do the same thing.

Professor Milne receives reports through the center of the earth by vibrations that travel about four hundred miles a second. This means twenty minutes for the trip. Such a speed shows the rigidity of the earth to be greater than any metal or other substance scientists have knowledge of — "two and one-half times that of glass, for instance," says Professor Milne, "and glass is more rigid than the finest steel." This was an interesting discovery, for it is an indorsement of Lord Kelvin's egg demonstration.

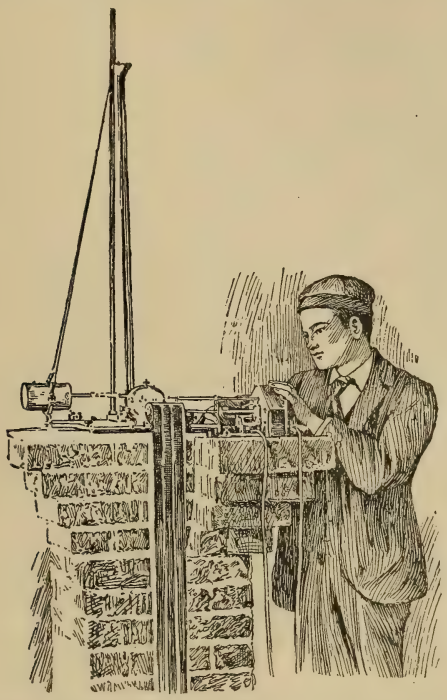
Lord Kelvin used to illustrate his idea of a solid rather than a liquid interior for the earth by spinning two eggs, one raw and the other hard-boiled. The hard-boiled egg spun much the longer time. In fact, the raw egg wobbled and stopped in a moment. Would not the earth have stopped spinning on its axis long ago, and could it possibly send earthquake dispatches through its very center, if it were not solid within?

In reading the signatures of the different earthquakes, it is interesting to compare the writings. The form of a signature — or perhaps it would be more accurate to say the form of the combination of signatures made by joining together the one that travels through the earth with the one that travels round it — gives a very clear idea of the distance the vibrations have traveled. Take the ones from Alaska, for example. Professor Milne has had many reports from that far-away region. He did not know, of course, where the quake was from until he had seen the record in his stable, and had compared it with signatures from other parts of the world, but he knew how far away it was. The other signatures that helped him out came from stations where observers had set up his seismographs.

There are some thirty of these stations scattered about the world: in North and South America, Europe, Asia, and Africa. Among those that helped particularly to fix the locality of these interesting shocks were Kew, Toronto, Victoria (British Colum-

bia), San Fernando (Spain), Bombay, Batavia, Mauritius, Madras, Calcutta, and Cape of Good Hope.

An interesting series of signatures from an Alaska earthquake of September 3, 1899, showing records from Toronto, San Fernando, Kew, Cape of Good Hope, Bombay, and Batavia, may be seen on page 345. This quake was from a region that has excited a great deal of interest lately — one that the professor



Shinobo Hiroba, Professor Milne's Assistant, Watching an Earthquake Write Its Signature.

looks upon as choice hunting-ground, albeit the "ground" is miles below the surface of the North Pacific Ocean. Ocean surveyors have not yet gone over this region thoroughly, but the professor believes that when they do they will find an enormous hole west of Yakutat Bay.

There is no telegraph communication between Yakutat Bay and the rest of the world, but there is excellent seismic com-

munication, as the signatures show. Professor Milne at Shide, ten thousand miles away from the center of disturbance, knew about it the day it happened. But it was not until September 25, a little over three weeks later, that the Toronto *World* had the news of three tidal waves on the coast of Alaska. Walls of water fifteen feet high rolled in upon the villages on the shore and well-nigh obliterated them. Islands sank many fathoms beneath the sea, so that now only the tops of their tallest trees show above the surface. On the Island of Kayak, just opposite Yakutat, there was a graveyard, which one may see distinctly now down through the clear water.

The ripples of the earth's crust that brought these signatures to Professor Milne's seismographs were from a foot to a foot and a half in height, and from twenty to thirty miles in length. They traveled at the rate of a little under two miles a second, and came along at intervals of about fifteen seconds. These ripples show large in the signatures, for they make the horizontal arms, the pen-holders of the seismographs, swing through a wider interval than do the more direct messages which come through the earth. The through messages are of a different kind from the surface ripples; they are tremors, series of contractions and expansions of the rigid material of the earth's inside. In the signature of an earthquake the distance from the starting-point of the through message to the starting-point of the surface message indicates the distance between the observatory and the center of disturbance.

In his report on the earthquakes of 1899, which the Royal Society Committee for Seismological Investigations will publish soon, Professor Milne, who is secretary for the Committee, says:

"Earthquakes from the same district will arrive at distant observing-stations at times, the distance between which will be constant. If for example we have once determined the difference in time at which an earthquake originating off the coast of Japan arrives at Batavia, Bombay, Cape of Good Hope, Shide, etc., whenever these differences are repeated at four or more stations, without knowing anything about observations in Japan, we can at once say where such an earthquake has originated. . . . If the large waves of an earthquake reach stations A, B, C, D, etc., the radii of which are respectively four times 1.6 degrees, then ten times 1.6 degrees, twenty times 1.6 degrees,

etc., will be the center of the origin required. The constant 1.6 degrees means that the actual velocity for large waves is taken at 1.6 degrees per minute, or about three kilometres (1.86 miles) a second. . . .

"The operation of drawing these circles is carried out on a slate globe. For a complete solution, observations are required from at least four stations. With only three observations we are left to choose between two possible centers, but as these may be widely separated there is usually little difficulty in selecting the one required."

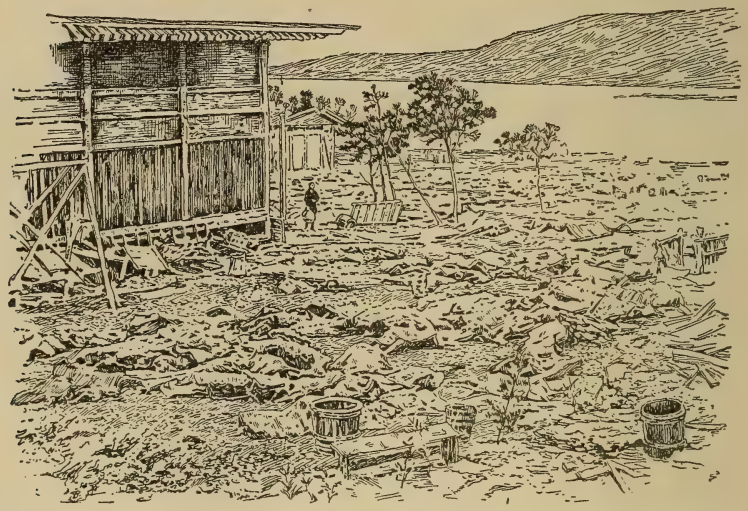
Sometimes Professor Milne receives the signature over again, showing on a smaller scale the preliminary tremors that have come through the earth, the great "shock" waves that have traveled round, the huge surface ripples, and then the waves of subsidence. These repetitions he calls "echoes." The waves of the earth-crust may rebound from some cliff or ledge, just as ripples are reflected from the edge of a pond back towards their center of the origin, or as sound waves are reflected from a wall.

Like sound waves, too, earthquake waves have rhythm, harmony and discord. Professor Milne has made use of the principle of discord in securing the safety of buildings. He has found the "pitch" of chimneys, for instance; that is, the period of their swaying. He treated the chimney as he would a tuning-fork of which he wished to determine the frequency of vibration. In the same way he got the "pitch" of houses. Then, knowing the frequency of earthquake vibrations, he made rules for building chimneys and houses out of tune with earthquakes. This prevented the house from "joining in." The chimney and the house must be in harmony, however, or there will be trouble in the household.

Professor Milne has had many occasions to point this out in the various foreign communities he is familiar with in earthquake countries. Often the house has broken itself to pieces by banging into a chimney that was vibrating a diminished fifth or a minor seventh below. Even a semitone is sometimes fatal, as was the case with several chimneys a builder had bound with iron bands to houses. When the shocks came the bands cut through the chimneys as if they were made of so much chalk instead of brick.

Japanese architecture has received much attention from the

Professor and also from his friend Josiah Condor, of the Institute of British Architects. From the studies of these experts it would seem that the statement that a people know better what is best for themselves than do outsiders is not absolute truth, for both Milne and Condor say that the ordinary Japanese house is anything but ideal, from the earthquake view-point, while Japan is the quakiest country in the world. The heavy roofs are bad. The tops of things should be light in Japan; but these roofs are always heavy, and when they get a-swinging they break off and crush everything in reach. After a bad earthquake in



After the Tidal Wave Thirty Thousand Bodies Lay Along the Coast of Japan.

Japan, the stricken district, as Professor Milne says, appears to be strewn with gigantic saddles. These are the fallen roofs. Again, it would be far better to tie rafters and beams and uprights together by iron bands than to mortise them. Mortising weakens the timbers and helps the weighty roof to come to earth.

The Professor's investigations with his seismographs and other instruments have been able to show the exact course of an earthquake particle during a shock, and Professor Seikiya, now occupying the chair of seismology in the Imperial Univer-

sity in Tokio, to represent this course has bent a wire. After looking at it one wonders how the earth holds together, why it does not float off as dust and lose itself in space. The wire looks like a matted tangle of yarn.

In the great Gifu quake of 1891 the earth, besides dropping twenty feet in sections of forty to sixty miles at a time, shook to-and-fro with frightful rapidity in quivering waves about a foot in width. There was an upward impetus to the earth particles also, despite the fact that the surface fell twenty feet. This had a rate of about four hundred feet a second. One effect of it was that houses weighted by heavy roofs sank up to the eaves, and another, that gateposts without top weights, and

Earthquake Signatures from the Great Alaska Shock of September 3, 1899, Recorded by Professor Milne's Instruments in Different Parts of the World.

therefore free to act, jumped about as though playing leapfrog. Some posts took a half-dozen jumps of four or five feet along the surface and then fell in their tracks. Occasionally one alighted so hard after the last jump that it remained upright ten yards from where it started, and in property where it had no business to be. A shock of the fifth of the force of the Gifu quake would demolish London in thirty seconds. Wooden houses in the suburbs might remain standing, however, for their construction affords some play.

The Charleston earthquake in 1886 was a severe one, and scientists have estimated something of its energy. Professor Milne says, speaking roughly, 24,000,000,000,000 foot-pounds for an

area ten miles square. To produce a shock of such force, let anyone drop a 24,000-ton ball from a height of 190 miles.

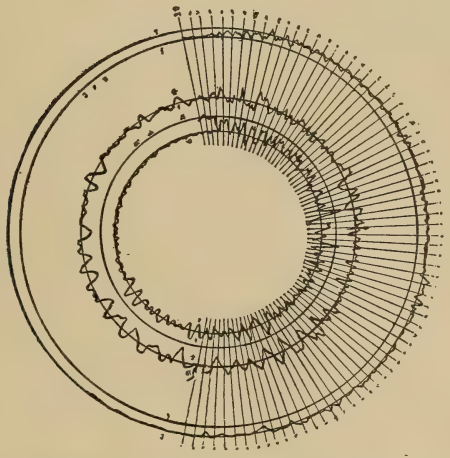
Professor Milne disclaims ability as an earthquake prophet, although he came to have something of a reputation in that line while in Japan. This was through his having distributed earthquake machines among his friends in various parts of the empire and asking them to collect records for him. They did so gladly, for the Professor's enthusiasm was contagious. Occasionally he would wire them from his home in Tokio, saying he had a premonition that a quake was at hand and warning them to be ready for it. As there are five to six hundred quakes a year in Japan, Professor Milne says it is not strange that occasionally his premonitions were correct. On one occasion he sent a message to some folk in Yokohama just in time. It was in 1881, and for several days the Tokio seismographs had been unusually quiet. "The calm before the storm," thought the Professor. So he sent his message, and soon after it reached its destination the earth began to shake and Yokohama had more excitement on its hands than it knew what to do with. It had not quaked so in years. The Milne message became famous and every one declared the Professor was genuinely a prophet.

Some went so far as to say that he had a personal influence over earthquakes; his appearance in any locality was a signal for everything to shake. Once, as he arrived at the Fujiya Hotel, Miyanoshita, a popular resort near Yokohama, a lady well known in Yokohama society greeted him with: "Oh, Professor Milne, I'm so glad to see you. You haven't any earthquakes with you, have you?" But, apparently, he had, for there was a lively one in evidence a moment later. Incidents like these are remembered and make a reputation for a man whether he wishes it or not, so that of the hundreds of foreigners Japan has in her employ probably none has a fame so widely spread as "Earthquake" Milne.

Although the seismograph does not foretell a quake, it can be of service, as the Professor points out, in giving warning of the tidal waves that often follow submarine earthquakes. These waves, which come in like a tremendously high tide, do vast damage. On the east shores of Japan in 1896 nearly thirty thousand persons perished in the sudden rising of the waters. Vessels out at sea sailed over the waves without any one on board

suspecting something unusual was taking place. The undulations were so broad and the rise so gentle that there was nothing to distinguish them from the ordinary surface of the sea. These waves travel at a rate that would take them across the Pacific in twenty-four hours. This is rapid traveling, but a warning which the seismograph could give at the time the wave started would afford plenty of time for coast dwellers to climb up out of the way.

Near Iquique there is a United States war vessel which has had a remarkable experience with tidal waves. On the first occasion, in 1868, a wave took her a mile inland, and later, in 1877, another wave carried her in two miles farther, where she still remains, although the family that has taken up its



An Earthquake Signature Written on a Circular Plate by the Fine Points of the Seismograph Fingers.

abode in her expect to get well across the country by the end of the present century.

In Australia there are two earthquake observatories, one at Sydney and another at Melbourne. It would have been a great deal of money saved to the colony if she had had a few of Professor Milne's instruments several years ago, when her three cables suddenly ceased to work and left her completely shut off from the world. There had been rumors of war, and

when the break occurred the Australians thought some hostile power had cut the cables and would soon swoop down upon the colonies. The Governors called out the Militia and the Naval Reserves to patrol the coast, and there was great excitement for nearly three weeks. Business was at a standstill until news came that it was only an earthquake, which had lowered the ocean's bottom, making the sea between Java and Australia deeper by many fathoms. The floor of the sea had taken down the cables along with it.

Professor Milne believes, from the experience he has had, that seismology will gain support from governments, from the great cable companies interested in learning the location of unstable regions in sea beds, and from private individuals who wish to advance scientific knowledge. Certainly its practical benefits are very obvious, and as a scientific pursuit there are few lines of investigation more fascinating.

HINTS TO INVENTORS.

By FRANCIS F. COLEMAN.

WHAT the inventor has done is marvelous enough; but, from our present standpoint, what he has not done is even more extraordinary. A glance at the problems still unsolved can hardly fail to fire the imagination.

First of all are the transportation improvements for which the world is waiting. Trains and ships which were marvels for speed a generation ago are hardly satisfactory for freights to-day, and our longings to annihilate space are the foundations of present efforts to build the flying machine. As the post-chaise speed of a century ago gave way to that of the sixty-mile-an-hour express train, so must this speed give way to the demands of a new century. We want Europe within two and one-half days' and San Francisco only one and one-half days' journey away.

Probably nothing has stood more in the way of such attainments than the absence of a true rotary steam-engine. With road-beds such as modern engineering has provided for our railroads, rails of steel, and smooth-running cars, there would seem to be almost no limit to the speed at which trains might be run with safety, but for the vibrations produced by the oscillating steam-engine. Although skilful mechanics have balanced these moving parts as perfectly as was possible, the locomotive engineer will tell you that long before his engine reaches a speed of a hundred miles an hour, its great mass is in a quiver from end to end and ready to fly from the tracks upon the slightest occasion. On high-speed steamships the vibrations of the engines are not only a source of great discomfort to passengers, but threaten the strength of the vessel itself. Although the inventor's quest for it has been long and arduous, the practicable rotary steam-engine still remains as "uninvented invention." The nearest approach to a solution is that offered by the steam turbine, and the use for that must be limited.

A true rotary engine has, however, been found in the electric motor. In the electric generator and motor are combined the two requisites for the ideal production and transformation of power. Not only are they capable of perfect balance and running without vibration, but they do away with the greater part of the loss of energy for which the steam-engine is notorious.

Here, then, is the means at hand for the inventor to meet the wants of modern traffic, while sticking close to earth and avoiding the dangers of "lighting," which must always attend every attempt to fly.

Electric cars have already attained speeds near to the one-hundred-miles-an-hour mark in safety, and it has been announced recently that the German Emperor has authorized the building of a road whereon it is intended that trains shall run at a speed of one hundred and fifty-five miles an hour. Air-ship traffic would find it hard to compete with this.

Railroading has already been a prolific source of profit to the inventor, but before speeds materially higher than those now used can be generally adopted, he must be called upon to again improve the railroad in its every member. The rail joint must either be abolished altogether, making the lines continuous by welded joints, as is done in the best street-railway practice, or a mechanical joint better than any yet made must be invented. But more important than all will be the methods of preventing collisions while dispatching trains at short intervals. Since electricity will be the motive power, it is possible that this may be so applied as to make it impossible for two trains to be run into each other even by intent. When one train approaches another within a given distance its power could be cut off automatically, and if it ran within another given distance the power could be reversed and brakes set.

Nothing must be left to chance when trains are flying along at a rate of more than 225 feet a second. Safety and economy must both be achieved, but there are also riches and honor to be won in that field.

Mr. Charles H. Parsons, of Great Britain, whose experimental boat, *Turbinia,* demonstrated the successful appliance of the steam turbine to the propulsion of vessels, has promised to build a ship to make fifty miles an hour whenever capitalists come forward to pay for her — and his torpedo-boat catchers, built

for the British Government, have shown his ability to keep his promise. Others have planned vessels to be driven by electric motors with power derived from vapor engines. This field offers as great promise to the inventor as the other. With ocean greyhounds making railroad speed over the face of the ocean, it is hardly probable that passengers could be persuaded to ride beneath the surface.

While certain inventors are achieving success in equipping railroads, ships, and factories with machinery to meet the demands of an exacting age, others bend their energies to solving the still more important problem of economizing coal or finding new sources of power.

Coal is King to-day. Whether we use steam engines, electric engines, gas-engines, compressed-air engines, or others to drive the wheels of industry, the one great source of energy is coal.

Five hundred million tons of coal a year are mined and transported to keep the world's furnaces aglow. Allowing for the usual waste in mining, this means a solid mass of coal that measures half a mile in length, breadth, and thickness. One hundred thousand men worked thirty years, it is estimated, to build the pyramid of Cheops; and yet the annual output of coal is equal in bulk to two hundred such pyramids!

Under the best conditions, we waste six-sevenths of the heat value of this fuel, and it may fairly be estimated that in general practice hardly the fifteenth part of its value is realized for actual work.

Here, then, is a field for the genius of the inventor wide enough to satisfy the most ambitious. First, the task is to draw from coal something like its real value in work, and next to find a substitute to provide against the time when the store-houses of coal, petroleum, natural gas, and other fuels shall be emptied. Thomas A. Edison, whose achievements in applied science have left him without a peer, and Nikola Tesla, the great necromancer in the field of electricity, have set for themselves the task of solving this problem, and mighty men of science in Europe are working toward the same end. Mr. Edison's aim is to find a way toward greater economy in the use of fuel. A bucketful of coal, he has declared, should drive an express train from New York to Philadelphia, and a few tons be sufficient for

the ocean steamship, where now her bunkers must hold thousands.

That there is hope for those who seek higher economies in the direct use of fuel is evidenced by advances already made. The boiler and steam-engine of a century ago, at its best, was capable of giving back but six per cent. of the energy of the coal, while to-day they return fourteen per cent., and coal turned into fuel-gases promises to give still higher results, when used through the medium of gas-engines, than can be had by turning its heat into steam.

Something of what we should be able to accomplish is indicated by figures.

In every pound of coal resides an energy which scientists express in heat units, each of which is capable of lifting 772 pounds one foot high. An average quality of coal contains 14,000 heat units, representing in round numbers 10,000,000 foot-pounds of energy. What work a pound of coal should do may be judged by comparing these figures with those which represent the labor of man and of a horse.

A hod-carrier, making his weary trips with brick and mortar, climbing stairs or a ladder, will in a day of ten hours exert 2,088,000 foot-pounds. One pound of coal burned under perfect conditions would do five times as much work.

A horse drawing a cart or plough expends 12,441,600 foot-pounds in the course of a day's work. The burning of one and one-quarter pounds of coal should do as much. The theoretical horse-power equals for ten hours but the proper consumption of 1.98 pounds of coal, and yet the best results secured in the largest steam plants still require the burning of one and one-half pounds of coal per hour for each horse-power produced.

Now, apply the same figures to a great steamer like the *Kaiser Wilhelm der Grosse,* which uses 30,000 horse-power to drive her across the Atlantic. She uses but about one and one-half pounds of coal per horse-power an hour. At that rate a five-and-one-half-day trip requires the burning of 2,870 tons of fuel. Nearly 2,500 tons of this might be saved if the theoretical value of the coal could be secured.

Here is a wide margin to be cut down, and every step in the right direction is certain to bring fortune to the inventor.

Two general methods for securing in power the higher values

of coal have been suggested. One is to get perfect combustion under circumstances where no heat shall be lost up the chimney or by radiation, and the other is to turn the fuel into electrical energy directly through the medium of some sort of a voltaic cell or battery.

Mr. Edison has taken up both ideas, and recently he described a mechanical device which he had designed in the former direction. He acknowledges that the idea came from using a German foot-warmer.

Mr. Edison's device consists of a double-walled furnace, between the walls of which compressed air is fed. Enough of this air is allowed to enter the inner enclosure to insure the combustion of fuel fed therein. The compressed air, absorbing heat from the burning fuel, expands and gives out its power through an engine, and this power is added to by the gases of combustion which join the air on its way to the engine. Mr. Edison declares that a loss of only about two per cent. of heat occurs in the apparatus.

Little progress has been made in the attempt to use coal as the active agent in the voltaic cell. Carbon shows little disposition to combine with oxygen except when heated, and then it prefers to burn in the ordinary way to being consumed in any sort of battery cell. Hot cells and cold cells have been tried. Cold cells have been definitely abandoned, and hot ones have given results not very encouraging.

Mechanical stokers have done much to economize coal, and invention is now busy trying to find a practicable way of feeding coal to the fires in a fine powder so as to secure perfect combustion without an excess of air.

But Tesla asks: Why should mankind use coal at all? John Ericsson long ago sought emancipation from the black king through a solar engine, and it was he also who led the way to the gas and motor engines, through the invention of the hot-air engine.

Tesla, however, would break away from fuel entirely. Throughout the earth are waterfalls, great and small, fed by waters sucked up by the sun's power, transported by the winds, and dropped on mountains and uplands, ready to give back the force which lifted them, in their descent to the sea.

Harness the waterfalls of the world by electricity, and make

them do your work, Tesla says; and already his discovery has set Niagara to driving the wheels of industry in Buffalo, and for use in cities far away. Waterfalls over many parts of the earth are being put to similar work.

Were these great water-powers situated where their energies are needed, the problem of using them would be simple. Then it would be a matter of mere cost. A ten-hour-a-day horse-power in the world's market is worth $20 a year. Hidden in the broken fastnesses of mountainous countries, far away from towns, are, however, many of the best water-powers, and these are useless unless their energies can be gathered up and transmitted with economy for long distances.

Using high voltages, electric lines are now built which convey hundreds of horse-power over wires hardly bigger than those of a long-distance telephone line, and many more are projected.

But although some of these lines are a hundred and fifty miles long, they do not yet fill the measure of Mr. Tesla's dream.

"I must send these energies hundreds, nay, thousands of miles," he has said, "and direct them at will. Wires are useful, but I must do this without wires. Then will the power of the sun do the world's work."

Mr. Tesla has already announced the discovery of a system by which to accomplish the transmission of electric power through the air, and without wires, but until he proves his theories by demonstration, the problem may still be counted as among the "uninvented inventions." Even when he makes the demonstration, it will merely open up a wider field to the general inventor.

Closely allied to the transmission of power without wires is the ever-interesting subject of telegraphing and telephoning without wires. Here is a field which should be prolific of new inventions. What Mr. Marconi has accomplished is but a beginning, and already the air is full of rumors of more wonderful inventions to come. This field is open to all comers.

One who has stood in Mr. Tesla's laboratory, and seen a vacuum tube glow like sunlight when held only in the great electrician's hand, knows that the problem of producing light without heat is nearly solved, but before those glowing tubes

can take the place of ordinary lights for home and shop, invention must be busy.

Looking upon those glowing tubes, and realizing that the light within is caused by clashing billions of electrified atoms, and then realizing that the X-ray which reveals our very bones is but another manifestation of like power, we find ourselves at the entrance of a new world, where science is merely treading the threshold.

Röntgen himself, though the discoverer of the mysterious rays that bear his name, called them X-rays because they represent a mysterious quantity in science.

Becquerel has since discovered that many natural substances emit rays like those of Röntgen, which make photographs in the dark and act as well through wood or metals. Thorium, uranium, bismuth, and barium, in various compounds, have been proved to have this quality, and they are also capable of exciting the phosphorescent screen used to render visible the disclosures of the X-rays. Here, then, is a suggestion of a new force more subtle than electricity, and perhaps destined to open to man fields hitherto not even dreamed of.

The witchery of modern science reached its highest point when it produced the telephone, which challenges the wonder of even those who use it daily. Yet, if appearances are not deceiving, the day is not far distant when, with instruments not so very different, we may see the friend a thousand miles away with whom we talk, or even photograph the scenes around him. Here is a field for the coming inventor which offers virgin soil. How it is to be conquered has only been remotely suggested.

Perhaps every substance in Nature emanates its own peculiar rays, and each of these may be able to make itself manifest on delicate instruments. Or perhaps the instrument for seeing afar may be made upon the principle that each color of light has its own effect, which may be caught on electrical conductors and transmitted afar, where each varied impulse may be sorted out like those of the quadruple telegraph, and made to reproduce its source in picture form. It was such an instrument which a Polish inventor promised to exhibit at the Paris Exposition, but he failed to keep his promise.

These, however, are speculations. Returning to the practical field, there is one invention still waiting for the right man, which

transcends in human importance all the others. To the man who solves this problem the world will owe wealth and honors such as no man yet has earned. It is the problem of restoring fertility to the worn-out fields of the world.

Perhaps when China's doors are thrown open the western world may learn from her valuable lessons as to how a teeming population can be fed for thousands of years without exhausting the soil. We may also get some lessons as to how a vast people can be governed solely through the power of philosophical teachings.

Western civilization, pushing ever into new lands, has left behind it a sterility of soil which, within a few years, has brought from the keenest scientific observers a most serious note of warning. A day of reckoning is almost at hand, when the earth will no longer be able to feed the people. There is no help to be had through farther pushing onward, for, vast as seem the parts of the earth yet unsettled, it is declared that in all that area there is little land which can profitably be brought under the dominion of the plough. For the older fields, which must be our dependence, one thing alone, the agricultural chemists declare, is necessary to bring them back to fertility. This is fixed nitrogen.

Vast fortunes have already been reaped by the "Nitrate Kings" of England from the nitrate deposits in Peru, and nations have warred for the possession of these fields.

Nitrogen is one of the most plentiful of elementary gases, but it is also one of the most difficult to fix. Spread about the whole world, forming three-quarters, by bulk and weight, of the atmosphere, it challenges man to bring it under subjection. The form in which the agriculturist most needs nitrogen is as sulphate of ammonia. Nature, through her mysterious processes, forms ammonia, which, floating about in the air, is gathered up by nitric acid formed by lightning flashes and carried in reviving showers to the earth, but this quantity is not sufficient to replace the drain upon cultivated fields.

Recent agricultural experiments have shown that about the roots of clover and other leguminous plants there gather colonies of microbes which feed the plants with nitrogen, and methods for restoring and maintaining fertility have been suggested

through cultivating these colonies. This field is now being explored.

Man, however, must have food, and his yearning stomach cannot wait. His safety lies in securing by artificial means an adequate supply of ammonia. Gas-houses, making illuminating gas from coal, are the principal sources of commercial ammonia, but the supply is so limited that the farmer can ill afford to buy.

Many ambitious attempts have been made to catch the flirtatious nitrogen of the air and turn it to commercial use. One of these, carried on at great expense and with persistence, was conducted within recent years under the leadership of William H. Bauldin, Jr., formerly of Baltimore. Success seemed almost assured, when an explosion in the works ended the life of their chief engineer, the late George H. Sellers, of Philadelphia, leaving the problem still unsolved.

Fame, as well as wealth, will be the reward of every man who helps the world a step forward in solving the problems outlined above, but the inventor who seeks money chiefly may gather it more easily through simpler tasks.

Lighten the labor of the housewife or the workman even by a trifle, or make a toy which tickles the fancy of an idle hour, and the world will pour gold into your coffers in a Midas stream. One cent drawn from each of seventy-five million persons makes three-quarters of a million dollars.

A cool-handled stove-lifter, a hook and eye with a hump or a spring, a shoe-lace fastener, a crook in a hair-pin, a glove fastener, "Pigs in Clover," the "Fifteen Puzzle," the return rubber-ball, Crandall's building blocks, the copper shoe-tip, are each examples of the success of little things, and no day passes that some new novelty might not be added to the list. Some were the results of study, but more the outcome of an inventive mind trying to meet a present want. It was merely a lazy boy who wanted time to play who put the first automatic valve gear on a steam engine and revolutionized the earlier practice of steam engineering.

Every home and workshop teems with profitable suggestions to the man with open eyes and mind.

The fortunes of Mr. Carnegie, the Rockefellers, the Armours, and all their associates were founded on just such observations. The cost of refining kerosene oil is paid to-day from the despised

sludge acid which used to foul our rivers and harbors. The old waste of the slaughter-houses brings in as much to-day as the flesh of the animals killed.

Nature has waste products still waiting for use. Prairie wire-grass was one of these. It is now made into handsome furniture and furnishings. Corn-stalk pith is made into fillings for war-ships' hulls, to close water-tight the holes made by an enemy.

Find a substitute for the elastic Para rubber, and your fortune is made. Celluloid and oxidized linseed oil are fair substitutes for some purposes, but nothing has yet been found that possesses the true elastic properties of rubber from Para. There is still "nothing like leather" for shoes, but the inventor may find a substitute to his profit.

The automobilist is waiting anxiously for a satisfactory power to drive his carriage. The same power would solve the vexed question of cross-town cars in New York. The Metropolitan Street Railway Company is spending thousands in experimenting with compressed air and storage battery cells, but these are only makeshifts. Steam railroads need a similar power to operate independent cars for suburban service.

Liquid air and acetylene gas both offer new fields for the inventor. Although liquid air can be made for perhaps five cents a gallon, as yet not a single commercial use has been found for it. Mr. Pictet, of Geneva, a pioneer in the liquefying of gases, has proposed to use the process for separating the nitrogen and oxygen of the air, and marketing each of these for special purposes. A factory in New York has the same objects in view. Carbonic-acid gas, frozen out of the atmosphere, would also be a product of the process.

In the heat of the electric furnace, lime and coal combine to form calcium carbide. This, slacked with water, resolves itself into lime and acetylene gas. Acetylene is one of the most fascinating of illuminants. Its flame, composed almost entirely of purple rays, glows white to the eye, and is many times as brilliant as that of street gas. Yet no way has been found to make it available for general lighting. It is used in isolated plants, but better appliances are still needed to render it safe and satisfactory.

Mr. Wilson, at his old mill in Virginia, made calcium car-

bide by accident, and discovered it only when a piece, kicked into the stream, began to bubble furiously.

Gas-makers paid him half a million dollars for his patents, believing that actylene could be used as a substitute for naphtha as an enricher for water-gas. They were disappointed. There are millions still waiting for the man who finds the needed substitute. Water-gas costs only about six cents a thousand cubic feet to manufacture, but until it is enriched by hydrocarbons it gives no light. Four to six gallons of naphtha to the thousand feet is cooked into it to make it an illuminant. Naphtha costs about six cents a gallon.

When the inventor has successfully solved the problems to which attention has herein been directed, and met each of the other demands of the day, he will but have broadened out his own field of labor.

Each new invention calls at once for more. The gas range, which has only just forced recognition for itself as a household necessity, cries out for the invention of proper utensils to use upon it.

Asphalt streets have set new tasks for the inventor. He must make new types of shoes to give easy and secure footing for horses, and new street-cleaning apparatus. With rougher pavements we were satisfied to get rid of the coarser dirt from the uneven surface, but now we are demanding apparatus that will rid our streets of dust as well.

Invention has entered intimately into every feature or our lives. From fabrics and foods every article in our stores shows the work of inventive genius, and suggests the possibility of further improvements. The grocer finds more than sixty per cent. of his wares all weighed, measured, and put up in packages for him, and the butcher, the baker, and greeengrocer each pay tribute to the inventor for conveniences which a few years ago were unthought of.

Upon such foundations the inventor of the future is to build, and the handsome fortunes which have rewarded those whose work is now before him give most solid assurance that his reward will be sure.

His field has no boundaries. Every forward step discloses new possibilities. The things which we use to-day as if we had always had them, were unthought of a generation ago, and

within another generation inventive talent will undoubtedly exploit still other realms of which we do not even dream.

> "There are more things in heaven and earth, Horatio,
> Than are dreamt of in your philosophy."

LOUIS PASTEUR.

LOUIS PASTEUR AND HIS WORK.

By PATRICK GEDDES AND J. ARTHUR THOMSON.

THOUGH there are kindly and thoughtful folk to whom the name of Pasteur has been a lifelong "red rag," and to whom it is a principle fixedly to oppose all that is tainted with vivisection or inoculation, even they must allow, if they take fair account of Pasteur's life and labors, that he was not always vivisecting or inoculating, that much of his work had nothing to do with either of these unpleasant operations, and that he has, apart from debated questions, done much to make the world richer and happier. We should ourselves be more enthusiastic, and shall be; but we make this initial recognition of possible dissent, from a conviction that it is neither trivial nor simply dealt with. Nor, indeed, can it be dealt with at all until the two parties take somewhat greater pains to understand one another.

To many a creative genius — poet, painter, musician, or inventor — death comes as an absolute full stop, as far as the continuity of his work is concerned. There may be immortality, but not continuance. It is otherwise, however, in the rarer cases of those to whose beneficent life is given the supreme fruition that it shall in a real sense continue after the individual has ceased to be. This reward is Pasteur's. For though he could not, of course, wholly throw his mantle over his school, endowing them with all his insight, practical sense and experimental genius, he had, years before his death, given them the keys with which he had himself opened so many doors. Discover the secret of tartrate fermentation, and the elucidation of a dozen others is but a matter of patience; overcome the silkworm disease, and some day diphtheria will be added to the list of solved problems; inoculate for splenic fever, and the cure of tuberculosis comes within sight. Though Pasteur is dead, his life thus continues.

It has been given to few to make so many discoveries of practical importance, after any one of which it might have been said he has deserved well of his country and paid his debt to mankind. He reformed the practice of vinegar-making and brewing, cured wine of its disorders, saved the silk industry not of France alone but of Europe, and showed how to drive out or to tame the germs of some of the most formidable diseases. But from the first, when he studied tartrates, to the last, when he wrestled with hydrophobia, his labors had two aspects — practical importance and speculative interest; and while we recognize that no man of science has been of greater economic service to his country, we must not forget how he changed the whole theory of fermentation, and played at least an important part in establishing the germ theory of disease.

Pasteur was born (December 27, 1822) in the *Rue des Tanneurs* of the little town of Dôle, in the Jura. His father had been a soldier, decorated on the field of battle, but he had left the ferment of war for the ferment of peace, and Louis Pasteur was thus a tanner's son. But this father was bookish and thoughtful, and the mother at once enthusiastic and shrewd, and there is no lack of evidence that they knew a great trust was given them in their child. When Louis was three years old the family removed to Arbois, where, by-and-by, the boy went to school, and, as one would expect, played truant freely, often angling, often making telling portraits of the neighbors. From Arbois he went for a year to the College of Besançon, where he rose at four in the morning, and gained his Bachelor of Letters diploma. It was there that his enthusiasm for chemistry was awakened. Leaving Besançon, where he had been a tutor as well as a student, he sat for the entrance examination to the École Normale in Paris. He passed fourteenth on the list; but, as this did not satisfy him, he withdrew for a year, worked hard by himself, was coached by an old schoolmaster, familiarly known as Père Barbet, and in the following year (1843) entered the famous school fourth on the list. There he studied chemistry under M. Balard, but, like his fellow-students, he also attended M. Dumas' course at the Sorbonne. Among others who influenced him much was M. Delafosse (a pupil and colleague of the famous mineralogist, Abbé Haüy), who infected Pasteur with his own enthusiasm for molecular

physics. Soon becoming known as a man of promise, he was called to Strasburg as Assistant Professor of Chemistry, and there he married the rector's daughter, Mdlle. Marie Laurent. At the age of thirty-two he was appointed Dean of the *Faculté des Sciences* at Lille, where the distilling industry of the district stimulated his already awakened interest in fermentation, and led to the famous series of researches in which he dealt successively with vinegar, wine, and beer. After three years' work at Lille, he was appointed (1857) as Director of Scientific Studies in his old college, the École Normale, in Paris — an institution which has had on its staff no small proportion of the best scientific men of France. In those days, however, science was still rather at a discount. "It was the period when Claude Bernard lived in a small damp laboratory, when M. Berthelot, though known through his great labors, was still nothing more than an assistant in the Collège de France." Thus Pasteur had to be content with a garret laboratory, some ten feet square, equipped at his own expense!

In 1865 he began the investigation of the calamitous silkworm disease, and in three years had virtually overcome it. But the *Peau de Chagrin* sadly shrinks with each fulfilment of our ambitions, and as the Nemesis of persistent overwork Pasteur had an attack of hemiplegia (1868). When in the midst of his labors spending much of his time in a hot greenhouse where the silkworms were kept, his physician had told him, "If you continue living in that place it may mean death; it certainly means paralysis." "Doctor," answered Pasteur, "I cannot give up my work; I am within sight of the end; I feel the approach of discovery. Come what may, I shall have done my duty." He was spared, however, to do more for his country, and even in the following year, when resting at the Prince Imperial's villa at Trieste, he vindicated practically the success of his work on silkworms by making for the villa a net profit of 26,000,000 fr., and that at a place "where for ten years the silk harvest had not sufficed to pay the cost of eggs."

Then came the year of the catastrophe: the strenuous spirit which well-nigh mortal illness had failed to bend was almost broken, and for a moment he lost heart for usual work amid the national grief. French patriotism, however, ever rises above despair, and work soon began afresh, stimulated now to a new

intensity, more perfervid yet more tenacious than ever. The student of contemporary history is familiar with the splendid reaction of Germany after what seemed the crushing disaster of Jena, and knows the part the universities took in it, and how seeds then sown sprang up not only in the armed victors of 1812-1814-1815, but more slowly in the fairer and more peaceful development of the German Universities, with all that they imply. But in England, in Germany, in France itself, people have still far too little appreciated the intensity of the resolution of the best men of 1870 — "Il faut refaire la patrie" — or know how much deeper, if less obvious, this has been than the much exaggerated cry of revenge, or even than the natural and inevitable desire for the recovery of the lost provinces, though these include French Lorraine as well as Teutonic Alsace. English and German writers are never weary of telling us of the decadence of France, or thanking Heaven that we are not as these Frenchmen; but there is another, if less prominent, side of French life and thought, as those who know it from within can testify, but which even the most cursory visitor to the great *expositions* of '78 or '89, the most careless tourist through the wine country, the most casual reader of French reviews should surely have seen. And it is as part of this national renascence, which is fundamentally not military but industrial, fundamentally not artistic or even scientific but moral, that Pasteur's life, work, and example, like those of many another quiet and non-political worker, have been given. This renascence is still of course only incipient, for a nation's life is not re-made in a single generation only; yet those are but superficial observers who can see in the strangely mixed present of France only the fruition of the evils of her past, but ignore the springing seed.

After the war Pasteur returned to his work at the Sorbonne, where he had been appointed Professor of Chemistry, and to his laboratory at the École Normale. The rest of his life is practically the story of his scientific work, of which his discoveries in connection with splenic fever and rabies are the most outstanding events. His was a temperament which made many enemies, but many friends also; and in his later years he had the satisfaction of seeing a school grow up around him — a reward greater than all the honors he received. Yet these were

not small, for in 1889, as the result of almost world-wide homage, the Pasteur Institute was opened. Its "Annales" contain the proof of industry but little abated by old age, and of a masterly power of inspiring others.

After a period of partial disablement, and another of paralysis, Pasteur died on September 28, 1895, in a quaint old house at Garches, which had been placed at his disposal for special researches. Thus he died, as he lived, in his laboratory; and if, as one of his countrymen puts it, there is one word more than other which his life suggests, it is the word *Labeur.**

The course of Pasteur's scientific work is one of remarkably natural and logical sequence. As the veteran M. Chevreuil long ago said in the Academy of Sciences, "It is by first examining in their chronological order the researches of M. Pasteur, and then considering them as a whole, that we appreciate the rigor of his conclusions, and the perspicacity of a mind which, strong in the truths which it has already discovered, sweeps forward to the establishment of what is new." We shall therefore summarize the record of his greatest achievements.

As was natural in a pupil of Dumas, Balard, and Delafosse, Pasteur's first important piece of work was chemical and crystallographic, and we may best understand its spirit by recalling the work of Delafosse's master in mineralogy, the Abbé Haüy, who is still remembered for that bold attempt to visualize the ultimate structure of the crystal, to penetrate the inmost secret of its architecture, which also re-appears in another way in the work of Mendeljeff. Pasteur's puzzle concerned the tartrates and paratartrates of soda and ammonia. These two salts are alike in chemical composition, in crystalline form, in specific gravity, and so on, but they differ in behavior. Thus, as Biot had shown, a solution of tartrate deflects the plane of polarized light passed through it, while a solution of the paratartrate does

* As to Pasteur's philosophic and religious conceptions we have a little information, though he who suffered so much in silence was not likely to talk of his faith. "Happy is he," he once said, "who has a god in his heart, an ideal of beauty, to which obedience is rendered; the ideal of art, the ideal of science, the ideal of country, the ideal of the Gospel virtues, these are the living sources of great thoughts and great actions." His utterances at the Edinburgh Tercentenary, and at his reception at the Academy are well known. There is another more dogmatic utterance of his, which we quote from an article by M. Jean Songère: "Quand on a bien étudié, on revient à la foi du paysan breton. Si j'avais étudié plus encore, j'aurais la foi de la paysanne bretonne."

not. The salts are the same, yet they behave differently. A note to the Academy from the famous chemist Mitscherlich emphasized the entire similarity of the two salts, and this acted as an additional stimulus to Pasteur. He succeeded in distinguishing the minute facets which even Mitscherlich had missed, he proved that the paratartrate is a combination of a left-handed and a right-handed tartrate, and did much else which only the expert chemist could duly explain. Biot was first doubtful, then delighted; Arago, who had also busied himself with these matters, moved that Pasteur's paper be printed in the memoirs of the Academy, and Mitscherlich himself congratulated the young discoverer who had tripped him up.

Already, then, in this minute and laborious piece of work we may detect that ultra-microscopic mental vision, and that rigorous accuracy so characteristic of the man. Yet it is interesting to observe that at this early stage he was sowing his wild oats of speculation. Impressed by the strange rotation of the plane of polarization exhibited by these organic salts, he educed therefrom an hypothesis of molecular disymmetry, and hazarded the view that this was a fundamental distinction between the organic and the inorganic. For various reasons, neither chemist nor biologist would nowadays accept this distinction; but it is hard to tell what Pasteur might have made of this inquiry had not circumstances, regretted at the time, directed his attention to very different subjects.

Being thus known in connection with tartrates, Pasteur was one day consulted, so the story goes, by a German manufacturer of chemicals, who was puzzled by the fermentation of his commercial tartrate of lime, which contained some admixture of organic impurities. Pasteur undertook to look into the matter, and probably deriving some hint from the previous work of Cagniard Latour and Schwann, who had demonstrated the yeast-plant which causes alcoholic fermentation, he demonstrated the micro-organism which fermented the tartrate of lime. He extended this discovery to other tartrates, and made the neat experiment of showing how the common blue mold (*Penicillium glaucum*), sown in paratartrate of ammonia, uses up all the right-handed tartrate, and leaves the left-handed salt alone, its identical chemical composition notwithstanding. These and similar inquiries led him to tackle the whole question of fer-

mentation, but his transference to Lille had probably much to do with this. For, as one of the chief industries of the district is making alcohol from beetroot and grain, Pasteur's practical sense led him to devote some of his lectures to fermentation; here, as always, as his biographer reminds us, wishful to make himself directly useful to his hearers.

The prevalent theory of fermentation, before Pasteur took the subject in hand, was that of Willis and Stahl, revised and elaborated by Liebig. According to this theory, nitrogenous substances in a state of decomposition upset the molecular equilibrium of fermentable matter with which they are in contact. What Pasteur did was to show that lactic, butyric, acetic, and some other fermentations were due to the vital activity of micro-organisms. In spite of Liebig's prolonged opposition, Pasteur carried his point; and although some of his detailed interpretations have since been revised, it is universally admitted that he changed the whole complexion of the fermentation problem. It must, of course, be borne in mind that his theory of the vital nature of many fermentations does not apply to soluble ferments or enzymes — such as diastase and pepsin — which are chemical substances, not living organisms. Part, indeed, of the opposition to Pasteur's views was due to the fact that this distinction between organized and unorganized ferments was not at the time clearly drawn. Perhaps, indeed, we are as yet by no means out of the wood.

In the course of his work on fermentation, Pasteur made an important theoretical step by distinguishing the micro-organisms which require the presence of free oxygen, from forms which are able to live apart from free oxygen, obtaining what they require by splitting up oxygen-containing compounds in the surrounding medium. These he termed aerobic and anaerobic respectively. Practically, this piece of work immediately led to what is known as the Orleans process of making vinegar. Some years later, after he had returned to Paris, he followed this up by his studies on wine, in the course of which he tracked various wine-diseases to their sources, and showed how deterioration might be prevented by raising the wine for a minute to a temperature of 50° C. The wine-tasters of Paris gave their verdict in his favor.

The old notion of spontaneous generation still lingered in

some quarters, and in 1858 Pouchet had given new life to the question by claiming before the Academy of Sciences that he had succeeded in proving the origin of microscopic organisms apart from pre-existing germs. But Pasteur knew more than Pouchet as to the insidious ways of germs: he showed the weak point of his antagonist's experiments, and gained the prize, offered in 1860 by the Academy, for "well-contrived experiments to throw new light upon the question of spontaneous generation." As every one knows, the victory was with Pasteur, but the idea is an old and recurrent one, and dies hard. Thus, not many years afterwards, Pasteur and Tyndall had to fight the battle over again with Bastian. The important result of what seems at first sight an abstract discussion has been not only an increased knowledge of the distribution and dissemination of bacteria, but the establishment of the fundamental conditions and methods of experimental bacteriology.

The transition from the study of ferments to the study of diseases was forced upon Pasteur by the pressure of a social event, the threatened collapse of the silk husbandry in France. But it was none the less a quite natural extension of his work; it was but a further inquiry into the part which micro-organisms play in nature. In 1849, after an exceptionally good year, a strange disease broke out in the silkworm nurseries in the south of France. The silkworms would not feed, or they failed in their last moulting; they died soon after birth, or even the eggs would not hatch; in short, everything went wrong. The disease spread and became an epidemic; and year after year the pest spoiled the silk farmer's harvest. All sorts of remedies were tried in vain; the only relief was found in the importation of fresh stock. Spain, Italy, and other European countries suffered, and at length in 1864 it was said that Japan alone was free from the disease. The industry, so important in some departments of France, was threatened with entire collapse; and to many *pébrine* had already spelt ruin. Memorials to the Senate led to the appointment of a Commission, with M. Dumas as its secretary. It was he who thought of appealing to his old student, Pasteur, and who eventually succeeded in persuading him to leave his ferments and enter upon a new path. The story has often been told that when Pasteur objected, saying that he had never even handled a silkworm, Dumas replied,

that was so much the better; it meant freedom from preconceptions.

As a matter of fact, however, Pasteur had his preconception, and the right one. The fermentations he had studied were due to micro-organisms, why not also this disease? And he was also aware that some Italian naturalists had discovered "peculiar microscopic corpuscles" in the diseased eggs, worms, and moths. A few hours after his arrival in Alais, on June 6, 1865, Pasteur demonstrated these corpuscles, and the first step was thus secure. With unsparing industry he traced them through all the phases of the insect's life; he infected the silkworms by spreading some of the corpusculous matter on the leaves they ate; he inoculated others and showed how they infected their neighbors by scratching them; he dealt in a similar way with a second disease called *flacherie;* and finally, as the outcome of his work — which is still a remarkable object-lesson, as it then was for himself, as to the treatment of other contagious diseases — he came to the conclusion that the only escape from the scourge was through the isolation of the healthy stock and the rigid elimination of the diseased. "If you use eggs," he said, "produced by moths, the worms of which have proved their health by climbing with agility up to the twigs on which they form their cocoons, if they have shown no signs of *flacherie* between the fourth moulting and this time, and which do not contain the least germ of *pébrine,* then you will succeed in all your cultivations." The art of distinguishing the healthy and unhealthy was soon learned, and in spite of the usual opposition, Pasteur and the microscope saved the silk industry.

As soon as his health had partially recovered from the attack of paralysis already mentioned, Pasteur returned to his study of ferments, and did for beer what he had already done for wine. He distinguished from the true yeast plant other micro-organisms, apt to be associated with it, which cause sourness and other diseases of beer. A prime condition of good beer is obviously therefore good yeast; the brewer therefore must learn to use his microscope. That the important brewers soon took the hint goes without saying; rapidly the microscope has found its place — in result and often in daily application — in the brewery; and it is now making its way into the bakery and the dairy as well.

Getting next to closer grips with life and death, Pasteur attacked the problem of splenic fever or anthrax. To this disease many animals, sheep, cattle, horses, and the like are liable; and in pastoral countries it may spread rapidly, and has often attained the dimensions of a plague. Thus the Ostiak herdsman who was rich in countless head of reindeer may find himself reduced to poverty in a season, or the Hungarian shepherd prince well nigh lose his flocks. Nor is man exempt. As far back as 1850 Davaine and Rayer had observed microscopic rods in the blood of animals which had died from splenic fever, but they did not follow up their discovery; in 1863, doubtless stimulated by Pasteur's researches on micro-organisms, Davaine had affirmed that the microbe was the cause of the disease, but his conclusion did not meet with general acceptance; again thirteen years elapsed, and in 1876 Dr. Koch made his first step to fame by satisfactorily proving that splenic fever was due to *Bacillus anthracis.*

Pasteur confirmed Koch's work with independent observations and experiments and advanced beyond it. Thus with his usual insight he explained that the immunity of birds from anthrax was due to their high temperature (41°–42° C.), which is near the limit (44° C.) at which the multiplication of *Bacillus anthracis* is inhibited in infusions. He chilled a fowl to 37° or 38° C., and inoculated it; it died in twenty-four hours. Again he inoculated a chilled fowl, let the fever develop, placed the bird wrapped in cotton wool in a chamber at 45° C., and saved it: As Professor Tyndall says in his vivid sketch of Pasteur's work: "The sharpness of the reasoning here is only equaled by the conclusiveness of the experiment, which is full of suggestiveness as regards the treatment of fevers in man." The current explanation of relapsing fevers is in fact dependent upon this.

A minor episode concerning fowl-cholera is important here in following the logical progress of Pasteur's work. As others had done, he recognized the microbe at work; but he did more, he tamed it. By cultivating it exposed to air, he produced an attenuated or weakened form, and by inoculating fowls with this he saved them from falling victims should they afterwards become infected with the "untamed" or virulent form. Jenner had, of course, reached a parallel result, protecting us from

the virulence of small-pox by inoculations with the milder microbe of cow-pox; but it should be carefully noticed that Pasteur's method was quite different. He attenuated the virus of the dreaded disease itself, and inoculated with that — a striking instance of *similia similibus curantur.*

With this new clue he returned to splenic fever, cultivated the bacillus exposed to air at a temperature of 42°-43° C.— at which no spores are formed — and obtained again an attenuated virus. Confident of each step, he boldly accepted the test of a public experiment, which resulted in what we may call the victory of Mélun. The Society of Agriculture there placed at his disposal sixty sheep and ten cows; ten sheep were to receive no treatment, twenty-five were to be inoculated with the attenuated vaccine; and these, along with the other twenty-five, were eventually to be infected with the virus of virulent splenic fever; similarly with the cows. On June 2, 1881, over two hundred experts and others met at Mélun to witness the result. Out of the twenty-five sheep which had not been vaccinated, twenty-one were dead; two others were dying; the non-vaccinated cows were fevered and off their food; the vaccinated cows had not suffered an elevation of temperature, and were eating quietly. One cannot wonder at "the shout of admiration" which arose from the witnesses of this dramatic experiment. The result was a wide use of vaccine and a reduction of the mortality from splenic fever, which yearly gives the economic justification of the literal hecatomb of its initiation.

To what he had thus achieved in connection with splenic fever, Pasteur made another important addition. He showed by careful experiments that when animals which had died of anthrax were buried in certain soils, the splenic germs lived on; the earth-worms brought them to the surface in their castings, and dissemination recommenced. Therefore, as he said, "we should never bury animals in fields destined either for cultivation, for forage, or for sheep pasture." When it is possible, a sandy soil should be chosen for the purpose, or any poor calcareous soil, dry, and easily desiccated — in a word, soil not suited to the existence of earth-worms. Thus Darwin and Pasteur meet in the study of earth-worms and the part they play in the intricate web of life. The part of worms in spreading

other epidemics — e. g., yellow fever — is now also under investigation.

Opposition was an ever recurrent factor in Pasteur's life. He had to fight for his crystallographic and chemical theories, and for his fermentation theory; he had to fight against the theory of spontaneous generation, and for his practice in inoculating as a preventive against splenic fever; he had to fight for each step. But no part of his work has met with so much opposition and adverse criticism as that concerning hydrophobia, though it is easy to exaggerate the importance of the discussion, in which Pasteur himself took little part.

While avoiding controversy and partisanship as far as may be, the question remains, What did Pasteur do in regard to hydrophobia? His claims are to have proved, first of all, that the disease was particularly associated with the nervous system. The virus is usually spread through the saliva, but it is not found in the blood or lymph, and it has its special seat in the nerves, brain, and spinal cord. Secondly, he showed that the virus might be attenuated in its virulence. The spinal cord of a rabbit which has died of rabies is, when fresh, powerfully virulent, but when exposed for a couple of weeks to dry air at a constant temperature of 23°-24° C. it loses its virulence. Thirdly, he showed that inoculation with the attenuated virus rendered an animal immune from infection with rabies. To make the animal immune it has first to be inoculated with infected spinal cord fourteen days old, then with that of thirteen days, and so on till inoculation with almost freshly infected spinal cord is possible. In this way the animal becomes refractory to the infection, and if it be bitten it will not die. Fourthly, he showed that even if the organism had been bitten, it was still possible to save it, unless the wounds were near the head — that is, within close reach of the central nervous system. For in the case of a superficial wound, say on hand or leg, the virus takes some considerable time to spread, and during this period of spreading and incubation it is possible to forestall the virus by inoculation with that which has been attenuated. In this case there is obvious truth in the proverb, "*Bis dat qui cito dat.*" And the outcome was that while out of a hundred persons bitten, nineteen or twenty will, in ordinary circumstances, die, "the mortality amongst cases treated at the Pas-

teur Institute has fallen to less than ½ per cent." According to another set of statistics, a mortality of 40 per cent. has been reduced to 1.3 per cent.; and of 1673 patients treated by Pasteur's method only 13 died.

As to the adverse criticism of Pasteur's inoculation against rabies, it consists, first and second, of the general argument of the anti-vivisectionists and the anti-vaccinationists, and thirdly, of specific objections. To the two former the school of Pasteur, of course, replies that the value of human life answers the one, and the results of experience the other; but on these controversies we cannot enter here. The main specific objections we take to be three — that as the micro-organism of rabies has not really been seen, the theory and practice of Pasteur's anti-rabic method lack that stability which is desirable; that the statistics in favor of the Pasteur procedure have been insufficiently criticised; that there have been failures and casualties, sometimes of a tragic nature. In regard to this last point — that deaths have occurred as the result of the supposed cure, instead of from the original infection — we may note that the *possibility* of such casualties was admitted by the English Investigation Committee (1887), while, on the other hand, Dr. Armand Ruffer, who speaks with much authority, denies with all deliberateness that there is any known case in which death followed as the result of Pasteur's treatment.

Microscopic verification is, of course, most desirable, and statistics are proverbially difficult of criticism. But, on the whole, we think it likely that those who, like ourselves, are not medical experts will incline to believe that Sir James Paget, Dr. Lauder Brunton, Professor George Fleming, Sir Joseph Lister, Dr. Richard Quain, Sir Henry Roscoe, and Professor Burdon Sanderson must have had grounds for saying, in the report which they presented to Parliament in 1887, "It may, hence, be deemed certain that M. Pasteur has discovered a method of protection from rabies comparable with that which vaccination affords against infection from small-pox."

So far a summary of Pasteur's personal life and scientific work, but is it not possible to make a more general and rational estimate of these? So much was his life centered in Paris that most are probably accustomed to think of him as a townsman; but it is more biologically accurate to recognize him as a rustic,

sprung from a strong, thrifty stock of mountain peasants. Nor can his early rustic environment of tanyard and farm, of village and country-side, be overlooked as a factor in developing that practical sense and economic insight which were so conspicuous in his life work. The tanner's son becomes the specialist in fermentation; the country boy is never throughout his life beyond hail of the poultry-yard and the farm-steading, the wine-press and the silk nursery; brought up in the rural French atmosphere of careful thrift and minute economies, all centered not round the mechanism or exchange of town industries, but round the actual maintenance of human and organic life, he becomes a great life-saver in his generation.

In short, as we might almost diagrammatically sum it up, the shrewd, minutely careful, yet inquiring rustic, eager to understand and then to improve what he sees, passes in an ever-widening spiral from his rural center upwards, from tan-pit to vat and vintage, from manure-heaps, earthworms, and water-supply to the problems of civic sanitation. The rustic tragedies of the dead cow and the mad dog excite the explanation and suggest the prevention of these disasters; from the poisoning of rats and mice he passes to suggestive experiments as to the rabbit-pest of Australia, and so in other cases from beast to man, from village to State. And on each radius on which he paused he left either a method or a clue, and set some other inquirer at work. On each radius of work he has left his disciples; for he founded not only an Institute, but a living school, or indeed whole schools of workers. We think of him, then, not only as a thinking rustic, but as one of the greatest examples in science of the Rustic as Thinker — a type of thinker too rare in our mechanical and urban generation, yet for whom the next generation waits.

As to his actual legacy to the world, let us sum it up briefly. There is the impulse which he gave, after the successful organization of his own Institute, to the establishment in other countries of similar laboratories of preventive medicine, and, one may also say, of experimental evolution. There is his educative work at Strasburg and Lille, at the École Normale and the Sorbonne, and, above all, in the smaller yet world-wide circle of his immediate disciples. To general biology his chief contribution has been the demonstration of the part which bac-

teria play, not only in pathological and physiological processes, but in the wider drama of evolution. To the chemist he has given a new theory of fermentation; to the physician many a suggestive lesson in the etiology of diseases, and a series of bold experiments in preventive and curative inoculation, of which Roux's treatment of diphtheria and Professor Fraser's new remedy for snake-bite are examples at present before the public; to the surgeon a stable foundation, as Lister acknowledged, for antiseptic treatment; to the hygienist a multitude of practical suggestions concerning water-supply and drainage, disinfection and burial. On brewer, distiller, and wine-maker he has forced the microscope and its results; and he has shown both agriculturist and stock-breeder how some, at least, of their many more than ten plagues may be either averted or alleviated.

In short, he has played a foremost part in the war against bacteria, in the elimination of the eliminators. But this raises the further question, too wide for discussion here — What processes of intelligent selection are to take the place of those too indiscriminating ones which are disappearing before the rapid progress of preventive medicine and hygiene? Here is the best evidence and measure of scientific discovery, that it raises new questions; in Pasteur's case, one essential to the future of civilization.

THE DISCOVERY OF ANÆSTHETICS.

By SIR JAMES PAGET, M. D.

THE history of the discovery of methods for the prevention of pain in surgical operations deserves to be considered by all who study either the means by which knowledge is advanced or the lives of those by whom beneficial discoveries are made. And this history may best be traced in the events which led to and followed the use of nitrous oxide gas, of sulphuric ether, and of chloroform as anæsthetics — that is, as means by which complete insensibility may be safely produced and so long maintained that a surgical operation, of whatever severity and however prolonged, may be absolutely painless.

In 1798, Mr. Humphry Davy, an apprentice to Mr. Borlase, a surgeon at Bodmin, had so distinguished himself by zeal and power in the study of chemistry and natural philosophy, that he was invited by Dr. Beddoes, of Bristol, to become the "superintendent of the Pneumatic Institution which had been established at Clifton for the purpose of trying the medicinal effects of different gases." He obtained release from his apprenticeship, accepted the appointment, and devoted himself to the study of gases, not only in their medicinal effects, but much more in all their chemical and physical relations. After two years' work he published his *Researches, Chemical and Philosophical, chiefly concerning Nitrous Oxide,* an essay proving a truly marvelous ingenuity, patience, and courage in experiments, and such a power of observing and of thinking as has rarely if ever been surpassed by any scientific man of Davy's age; for he was then only twenty-two.

In his inhalations of the nitrous oxide gas he observed all the phenomena of mental excitement, of exalted imagination, enthusiasm, merriment, restlessness, from which it gained its popular name of "laughing gas"; and he saw people made, at least for some short time and in some measure, insensible by it. So,

among other suggestions or guesses about probable medicinal uses of inhalation of gases, he wrote, near the end of his essay: "As nitrous oxide in its extensive operation appears capable of destroying physical pain, it may probably be used with advantage during surgical operations in which no great effusion of blood takes place."

It seems strange that no one caught at a suggestion such as this. True, the evidence on which it was founded was very slight; it was with a rare scientific power that Davy had thought out so far beyond his facts; but he had thought clearly, and as clearly told his belief. Yet no one earnestly regarded it. The nitrous oxide might have been of as little general interest as the carbonic or any other, had it not been for the strange and various excitements produced by its inhalation. These made it a favorite subject with chemical lecturers, and year after year, in nearly every chemical theater, it was fun to inhale it after the lecture on the gaseous compounds of nitrogen; and among those who inhaled it there must have been many who, in their intoxication, received sharp and heavy blows, but, at the time, felt no pain. And this went on for more than forty years, exciting nothing worthy to be called thought or observation, till, in December, 1844, Mr. Colton, a popular itinerant lecturer on chemistry, delivered a lecture on "laughing gas" in Hartford, Connecticut. Among his auditors was Mr. Horace Wells, an enterprising dentist in that town, a man of some power in mechanical invention. After the lecture came the usual amusement of inhaling the gas, and Wells, in whom long wishing had bred a kind of belief that something might be found to make tooth-drawing painless, observed that one of the men excited by the gas was not conscious of hurting himself when he fell on the benches and bruised and cut his knees. Even when he became calm and clear-headed the man was sure that he did not feel pain at the time of his fall. Wells was at once convinced — more easily convinced than a man of more scientific mind would have been — that, during similar insensibility, in a state of intense nervous excitement, teeth might be drawn without pain, and he determined that himself and one of his own largest teeth should be the first for trial. Next morning Colton gave him the gas, and his friend Dr. Riggs extracted his tooth. He remained unconscious for a few moments, and then exclaimed,

"A new era in tooth-pulling! It did not hurt me more than the prick of a pin. It is the greatest discovery ever made."

In the next three weeks Wells extracted teeth from some twelve or fifteen persons under the influence of the nitrous oxide, and gave pain to only two or three. Dr. Riggs, also, used it with the same success, and the practice was well known and talked of in Hartford.

Encouraged by his success Wells went to Boston, wishing to enlarge the reputation of his discovery and to have an opportunity of giving the gas to some one undergoing a surgical operation. Dr. J. C. Warren, the senior Surgeon of the Massachusetts General Hospital, to whom he applied for this purpose, asked him to show first its effects on some one from whom he would draw a tooth. He undertook to do this in the theater of the medical college before a large class of students, to whom he had, on a previous day, explained his plan. Unluckily, the bag of gas from which the patient was inhaling was taken away too soon; he cried out when his tooth was drawn; the students hissed and hooted; and the discovery was denounced as an imposture.

Wells left Boston disappointed and disheartened; he fell ill, and was for many months unable to practice his profession. Soon afterwards he gave up dentistry, and neglected the use and study of the nitrous oxide, till he was recalled to it by a discovery even more important than his own.

The thread of the history of nitrous oxide may be broken here.

The inhalation of sulphuric ether was often, even in the eighteenth century, used for the relief of spasmodic asthma, phthisis, and some other diseases of the chest. Dr. Beddoes and others thus wrote of it: but its utility was not great, and there is no evidence that this use of it had any influence on the discovery of its higher value, unless it were, very indirectly, in its having led to its being found useful for soothing the irritation produced by inhaling chlorine. Much more was due to its being used, like nitrous oxide, for the fun of the excitement which its diluted vapor would produce in those who freely inhaled it.

The beginning of its use for this purpose is not clear. In the *Journal of Science and the Arts,* published in 1818 at the Royal Institution, there is a short anonymous statement among the "Miscellanea," in which it is said, "When the vapor of ether

mixed with common air is inhaled, it produces effects very similar to those occasioned by nitrous oxide." The method of inhaling and its effects are described, and then "it is necessary to use caution in making experiments of this kind. By the imprudent inspiration of ether a gentleman was thrown into a very lethargic state, which continued with occasional periods of intermission for more than thirty hours, and a great depression of spirits; for many days the pulse was so much lowered that considerable fears were entertained for his life."

The statement of these facts has been ascribed to Faraday, under whose management the journal was at that time published. But, whoever wrote or whoever may have read the statement, it was, for all useful purposes, as much neglected as was Davy's suggestion of the utility of the nitrous oxide. The last sentence, quoted as it was by Pereira and others writing on the uses of ether, excited much more fear of death than hope of ease from ether-inhalation. Such effects as are described in it are of exceeding rarity; their danger was greatly over-estimated; but the account of them was enough to discourage all useful research.

But, as the sulphuric ether would "produce effects very similar to those occasioned by nitrous oxide," and was much the more easy to procure, it came to be often inhaled, for amusement, by chemists' lads and by pupils in the dispensaries of surgeons. It was often thus used by young people in many places of the United States. They had what they called "ether-frolics," in which they inhaled ether till they became merry, or in some other way absurdly excited or, sometimes, completely insensible.

Among those who had joined in these ether-frolics was Dr. Wilhite, of Anderson, South Carolina. In one of them, in 1839, when nearly all of the party had been inhaling and some had been laughing, some crying, some fighting — just as they might have done if they had had the nitrous oxide gas — Wilhite, then a lad of seventeen, saw a negro boy at the door and tried to persuade him to inhale. He refused and resisted all attempts to make him do it, till they seized him, held him down, and kept a handkerchief wet with ether close over his mouth. Presently his struggles ceased; he lay insensible, snoring, past all arousing; he seemed to be dying. And thus he lay for an hour, till medical

help came and, with shaking, slapping, and cold splashing, he was awakened and suffered no harm.

The fright at having, it was supposed, so nearly killed the boy, put an end to ether-frolics in that neighborhood; but in 1842 Wilhite had become a pupil of Dr. Crauford Long, practicing at that time at Jefferson (Jackson County, Georgia). Here he and Dr. Long and three fellow-pupils often amused themselves with the ether-inhalation, and Dr. Long observed that when he became furiously excited, as he often did, he was unconscious of the blows which he, by chance, received as he rushed or tumbled about. He observed the same in his pupils; and thinking over this, and emboldened by what Mr. Wilhite told him of the negro boy recovering after an hour's insensibility, he determined to try whether the ether-inhalation would make any one insensible of the pain of an operation. So, in March, 1842, nearly three years before Wells's observations with the nitrous oxide, he induced Mr. Venable, who had been very fond of inhaling ether, to inhale it till he was quite insensible. Then he dissected a tumor from his neck; no pain was felt, and no harm followed. Three months later, he similarly removed another tumor from him; and again, in 1842 and 1845, he operated on three other patients, and none felt pain. His operations were known and talked of in his neighborhood; but the neighborhood was only that of an obscure little town; and he did not publish any of his observations. The record of his first operation was only entered in his ledger:

"James Venable, 1842. Ether and excising tumor, $2.00."

He waited to test the ether more thoroughly in some greater operation than those in which he had yet tried it; and then he would have published his account of it. While he was waiting, others began to stir more actively in busier places, where his work was quite unknown, not even heard of.

Among those with whom, in his unlucky visit to Boston, Wells talked of his use of the nitrous oxide, and of the great discovery which he believed that he had made, were Dr. Morton and Dr. Charles Jackson, men widely different in character and pursuit, but inseparable in the next chapter of the history of anæsthetics.

Morton was a restless, energetic dentist, a rough man, resolute to get practice and make his fortune. Jackson was a quiet, scientific gentleman, unpractical and unselfish, in good repute

as a chemist, geologist, and mineralogist. At the time of Wells' visit, Morton, who had been his pupil in 1842, and for a short time in 1843 his partner, was studying medicine and anatomy at the Massachusetts Medical College, and was living in Jackson's house. Neither Morton nor Jackson put much if any faith in Wells' story, and Morton witnessed his failure in the medical theater. Still, Morton had it in his head that tooth-drawing might somehow be made painless, and even after Wells had retired from practice, he talked with him about it, and made some experiments, but, having no scientific skill or knowledge, they led to nothing. Still, he would not rest, and he was guided to success by Jackson, whom Wells advised him to ask to make some nitrous oxide gas for him.

Jackson had long known, as many others had, of sulphuric ether being inhaled for amusement, and of its producing effects like those of nitrous oxide; he knew also of its employment as a remedy for the irritation caused by inhaling chlorine. He had himself used it for this purpose, and once, in 1842, while using it, he became completely insensible. He had thus been led to think that the pure ether might be used for the prevention of pain in surgical operations; he spoke of it with some scientific friends, and sometimes advised a trial of it; but he did not urge it or take any active steps to promote even the trial. One evening, Morton, who was now in practice as a dentist, called on him, full of some scheme which he did not divulge, and urgent for success in painless tooth-drawing. Jackson advised him to use the ether, and taught him how to use it.

On that same evening, the 30th of September, 1846, Morton inhaled the ether, put himself to sleep, and, when he awoke, found that he had been asleep for eight minutes. Instantly, as he tells, he looked for an opportunity of giving it to a patient; and one just then coming in, a stout, healthy man, he induced him to inhale, made him quite insensible, and drew his tooth without his having the least consciousness of what was done.

But the great step had yet to be made — the step which Wells would have tried to make if his test experiment had not failed. Clearly, operations as swift as that of tooth-drawing might be rendered painless, but could it be right to incur the risk of insensibility long enough and deep enough for a large surgical operation? It was generally believed that in such insensibility

there was serious danger to life. Was it really so? Jackson advised Morton to ask Dr. J. C. Warren to let him try, and Warren dared to let him. It is hard now to think how bold the enterprise must have seemed to those who were capable of thinking accurately on the facts then known.

The first trial was made on the 16th of October, 1846. Morton gave the ether to a patient in the Massachusetts General Hospital, and Dr. Warren removed a tumor from his neck. The result was not complete success; the patient hardly felt the pain of cutting, but he was aware that the operation was being performed. On the next day, in a severer operation by Dr. Hayward, the success was perfect; the patient felt nothing, and in long insensibility there was no appearance of danger to life.

The discovery might already be deemed complete, for the trials of the next following days had the same success, and thence onwards the use of the ether extended over constantly widening fields. A coarse but feeble opposition was raised by some American dentists; a few surgeons were over-cautious in their warnings against suspected dangers; a few maintained that pain was very useful, necessary perhaps to sound healing; some were hindered by their dislike of the patent which Morton and Jackson took out; but as fast as the news could be carried from one continent to another, and from town to town, so fast did the use of ether spread. It might almost be said that in every place, at least in Europe, where the discovery was promoted more quickly than in America, the month might be named before which all operative surgery was agonizing, and after which it was painless.

But there were other great pains yet to be prevented, the pains of childbirth. For escape from these the honor and deep gratitude are due to Sir James Simpson. No energy, or knowledge, or power of language less than his could have overcome the fears that the insensibility, which was proved to be harmless in surgical operations and their consequences, should be often fatal or very mischievous in parturition. And to these fears were added a crowd of pious protests (raised, for the most part, by men) against so gross an interference as this seemed with the ordained course of human nature. Simpson, with equal force of words and work, beat all down; and by his adoption of chloroform as a substitute for ether promoted the whole use of anæsthetics.

Ether and chloroform seemed to supply all that could be wished from anæsthetics. The range of their utility extended; the only question was as to their respective advantages, a question still unsettled. Their potency was found absolute, their safety very nearly complete, and, after the death of Wells in 1848, nitrous oxide was soon neglected and almost forgotten. Thus it remained till 1862, nearly seventeen years, when Mr. Colton, who still continued lecturing and giving the gas "for fun," was at New Haven, Connecticut. He had often told what Wells had done with nitrous oxide at Hartford, and he wanted other dentists to use it, but none seemed to care for it till, at New Britain, Dr. Dunham asked him to give it to a patient to whom it was thought the ether might be dangerous. The result was excellent, and in 1863 Dr. Smith, of New Haven, substituted the nitrous oxide for ether in his practice and used it very frequently. In the nine months following his first use of it, he extracted without pain nearly 4,000 teeth. Colton, in the following year, associated himself with a dentist in New York and established the Colton Dental Association, where the gas was given to many thousands more. Still, its use was very slowly admitted. Some called it dangerous, others were content with chloroform and ether, others said that the short pangs of tooth-drawing had better be endured. But in 1867 Mr. Colton came to Paris and Dr. Evans at once promoted his plan. In 1868 he came to London and, after careful study of it at the Dental Hospital, the nitrous oxide was speedily adopted, both by dentists and by the administrators of anæsthetics. By this time it has saved hundreds of thousands of people from the sharp pains of all kinds of operations on the teeth and of a great number of the surgical operations that can be quickly done.

Such is the history of the discovery of the use of anæsthetics. Probably, none has ever added so largely to that part of happiness which consists in the escape from pain. Past all counting is the sum of happiness enjoyed by the millions who, in the last three-and-thirty years, have escaped the pains that were inevitable in surgical operations; pains made more terrible by apprehension, more keen by close attention; sometimes awful in a swift agony, sometimes prolonged beyond even the most patient endurance, and then renewed in memory and terrible in dreams. These will never be felt again. But the value of the discovery is

not limited by the abolition of these pains or the pains of childbirth. It would need a long essay to tell how it has enlarged the field of useful surgery, making many things easy that were difficult, many safe that were too perilous, many practicable that were nearly impossible. And, yet more variously, the discovery has brought happiness in the relief of some of the intensest pains of sickness, in quieting convulsion, in helping to the discrimination of obscure diseases. The tale of its utility would not end here; another essay might tell its multiform uses in the study of physiology, reaching even to that of the elemental processes in plants, for these, as Claude Bernard has shown, may be completely for a time suspended in the sleep produced by chloroform or ether.

And now, what of the discoverers?* What did time bring to those who brought so great happiness to mankind?

* * *

Probably most people would agree that Long, Wells, Morton and Jackson deserved rewards, which none of the four received. But that which the controversy and the patent and the employment of legal advisers made it necessary to determine was, whether more than one deserved reward, and, if more than one, the proportion to be assigned to each. Here was the difficulty. The French Academy of Sciences in 1850 granted equal shares in the Monthyon Prize to Jackson and to Morton; but Long was unknown to them, and, at the time of the award, the value of nitrous oxide was so hidden by the greater value of ether that

* Those only are here reckoned as discoverers from whose work may be traced not merely what might have been the beginning of the discovery, but the continuous history of events consequent upon the evidence of its truth. Long, it is true, might under this rule be excluded; yet his work cannot fairly be separated from the history. Of course, in this, as in every similar case, there were some who maintained that there was nothing new in it. Before 1842 there were many instances in which persons underwent operations during insensibility. There may be very reasonable doubts about what is told of the ancient uses of Indian hemp, and mandragora; but most of those who saw much surgery before 1846 must have seen operations done on patients during insensibility produced by narcotics, dead-drunkenness, mesmerism, large losses of blood, or other uncertain and often impracticable methods. Besides, there were many guesses and suggestions for making operations painless. But they were all fruitless; and they fail at that which may be a fair test for most of the claims of discoverers — the test of consequent and continuous history. When honor is claimed for the authors of such fruitless works as these, it may fairly be said that blame rather than praise is due to them. Having seen so far as they profess, they should not have rested till they could see much further.

Wells' claim was set aside. A memorial colmun was erected at Boston, soon after Morton's death in 1868, and here the difficulty was shirked by dedicating the column to the discovery of ether, and not naming the discoverers. The difficulty could not be thus settled; and, in all probability, our supposed council of four or five would not solve it. One would prefer the claims of absolute priority; another those of suggestive science; another the courage of bold adventure; sentiment and sympathy would variously affect their judgments. And if we suppose that they, like the American Congress, had to discuss their differences within sound of such controversies as followed Morton's first use of ether, or during a war of pamphlets, or under burdens of parliamentary papers, we should expect that their clearest decision would be that a just decision could not be given, and that gratitude must die if it had to wait till distributive justice could be satisfied. The gloomy fate of the American discoverers makes one wish that gratitude could have been let flow of its own impulse; it would have done less wrong than the desire for justice did. A lesson of the whole story is that gratitude and justice are often incompatible; and that when they conflict, then, usually, "the more right the more hurt."

Another lesson, which has been taught in the history of many other discoveries, is clear in this — the lesson that great truths may be very near us and yet be not discerned. Of course, the way to the discovery of anæsthetics was much more difficult than it now seems. It was very difficult to produce complete insensibility with nitrous oxide till it could be given undiluted and unmixed; this required much better apparatus than Davy or Wells had; and it was hardly possible to make such apparatus till india-rubber manufactures were improved. It was very difficult to believe that profound and long insensibility could be safe, or that the appearances of impending death were altogether fallacious. Bold as Davy was, bold even to recklessness in his experiments on himself, he would not have ventured to produce deliberately in any one a state so like a final suffocation as we now look at unmoved. It was a boldness not of knowledge that first made light of such signs of dying, and found that what looked like a sleep of death was as safe as the beginning of a night's rest. Still, with all fair allowance for these and other difficulties, we cannot but see and

wonder that for more than forty years of the nineteenth century a great truth lay unobserved, though it was covered with only so thin a veil that a careful physiological research must have discovered it. The discovery ought to have been made by following the suggestion of Davy. The book in which he wrote that "nitrous oxide — capable of destroying physical pain — may probably be used with advantage during surgical operations," was widely read, and it would be hard to name a man of science more widely known and talked of than he was. Within two years of the publication of his *Researches* he was appointed to a professorship in the Royal Institution; and in the next year he was a favorite in the fashionable as well as in the scientific world; and all his life through he was intimately associated with those among whom all the various motives for desiring to find some means "capable of destroying physical pain" would be most strongly felt. Curiosity, the love of truth, the love of marvels, the desire of ease, self-interest, benevolence, — all were alert in the minds of men and women who knew and trusted whatever Davy said or wrote, but not one mind was earnestly directed to the rare promise which his words contained. His own mind was turned with its full force to other studies; the interest in surgery which he may have felt during his apprenticeship at Bodmin was lost in his devotion to poetry, philosophy, and natural science, and there is no evidence that he urged others to undertake the study which he left. Even his biographers, his brother, Dr. John Davy, and his intimate friend, Dr. Paris, both of whom were very capable physicians and men of active intellect, say nothing of his suggestion of the use of nitrous oxide. It was overlooked and utterly forgotten till the prophecy was fulfilled by those who had never heard of it. The same may be said of what Faraday, if it were he, wrote of the influence of sulphuric ether. All was soon forgotten, and the clue to the discovery, which would have been far easier with ether than with nitrous oxide, for it needed no apparatus and even required mixture with air, was again lost. One could have wished that the honor of bringing so great a boon to men, and so great a help in the pursuit of knowledge, had been won by some of those who were giving themselves with careful cultivation to the search for truth as for its own sake. But it was not so: science was utterly at

fault; and it was shown that in the search for truth there are contingencies in which men of ready belief and rough enterprise, seeking for mere utility even with selfish purposes, can achieve more than those who restrain themselves within the range of what seems reasonable.

Such instances of delay in the discovery of truth are always wondered at, but they are not uncommon. Long before Jenner demonstrated the utility of vaccination it was known in Gloucestershire that they who had had cow-pox could not catch the smallpox. For some years before the invention of electric telegraphy, Professor Cumming of Cambridge, when describing to his class the then recent discovery by Oersted of the power of an electric current to deflect a magnet, used to say, "Here, then, are the elements which would excellently serve for a system of telegraphy." Yet none of his hearers, active and cultivated as they were, were moved from the routine of study. Laennec quotes a sentence from Hippocrates which, if it had been worthily studied, might have led to the full discovery of auscultation [trained listening to sounds]. Thus it often has been; and few prophecies can be safer than that our successors will wonder at us as we do at those before us; will wonder that we did not discern the great truths which they will say were all around us, within reach of any clear, earnest mind.

They will wonder, too, as we may, when we study the history of the discovery of anæsthetics, at the quietude with which habitual miseries are borne; at the very faint impulse to action which is given by even great necessities when they are habitual. Thinking of the pain of surgical operations, one would think that men would have rushed after the barest chance of putting an end to it as they would have rushed to escape from starving. But it was not so; the misery was so frequent, so nearly customary, deemed so inevitable, that, though it excited horror when it was talked of, it did not excite to strenuous action. Remedies were wished for and sometimes tried, but all was done vaguely and faintly; there was neither hope enough to excite intense desire, nor desire enough to encourage hope; the misery was "put up with" just as we now put up with typhoid fever and sea-sickness, with local floods and droughts, with the waste of health and wealth in the pollution of rivers, with hideous noises and foul smells, and many other miseries. Our successors, when

they have remedied or prevented them, will look back on them with horror, and on us with wonder and contempt for what they will call our idleness or blindness or indifference to suffering.

THE ART OF PROLONGING LIFE.

By ROBSON ROOSE, M. D.

THE doctrine that a short life is a sign of divine favor has never been accepted by the majority of mankind. Philosophers have vied with each other in depicting the evils and miseries incidental to existence, and the truth of their descriptions has often been sorrowfully admitted, but they have failed to dislodge, or even seriously diminish, that desire for long life which has been deeply implanted within the hearts of men. The question whether life be worth living has been decided by a majority far too great to admit of any doubt upon the subject, and the voices of those who would fain reply in the negative are drowned amid the chorus of assent. Longevity, indeed, has come to be regarded as one of the grand prizes of human existence, and reason has again and again suggested the inquiry whether care or skill can increase the chances of acquiring it, and can make old age, when granted, as comfortable and happy as any other stage of our existence.

From very early times the art of prolonging life, and the subject of longevity, have engaged the attention of thinkers and essayists; and some may perhaps contend that these topics, admittedly full of interest, have been thoroughly exhausted. It is true that the art in question has long been recognized and practiced, but the science upon which it really depends is of quite modern origin. New facts connected with longevity have, moreover, been collected within the last few years, and some of these I propose to examine, and further to inquire whether they teach us any fresh means whereby life may be maintained and prolonged.

But, before entering upon the immediate subject, there are several preliminary questions which demand a brief examination, and the first that suggests itself is, What is the natural duration of human life? This oft-repeated question has received

many different answers; and inquiry has been stimulated by skepticism as to their truth. The late Sir George Cornewall Lewis expressed the opinion that one hundred years must be regarded as a limit which very few, if indeed any, human beings succeed in reaching, and he supported this view by several cogent reasons. He pointed out that almost all the alleged instances of abnormal longevity occurred among the humbler classes, and that it was difficult, if not impossible, to obtain any exact information as to the date of birth, and to identify the individuals with any written statements that might be forthcoming. He laid particular stress upon the fact that similar instances were altogether absent among the higher classes, with regard to whom trustworthy documentary evidence was almost always obtainable. He thought that the higher the rank the more favorable would the conditions be for the attainment of a long life. In this latter supposition, however, Sir George Lewis was probably mistaken: the comforts and luxuries appertaining to wealth and high social rank are too often counterbalanced by cares and anxieties, and by modes of living inconsistent with the maintenance of health, and therefore with the prolongation of life. In the introduction to his work on "Human Longevity," Easton says, "It is not the rich or great . . . that become old, but such as use much exercise, are exposed to the fresh air, and whose food is plain and moderate — as farmers, gardeners, fishermen, laborers, soldiers, and such men as perhaps never employed their thoughts on the means used to promote longevity."

The French naturalist, Buffon, believed that if accidental causes could be excluded, the normal duration of human life would be between ninety and one hundred years, and he suggested that it might be measured (in animal as well as in man) by the period of growth, to which it stood in a certain proportion. He imagined that every animal might live for six or seven times as many years as were requisite for the completion of its growth. But this calculation is not in harmony with facts, so far, at least, as man is concerned. His period of growth cannot be estimated at less than twenty years; and if we take the lower of the two multipliers, we get a number which, in the light of modern evidence, cannot be accepted as attainable. If the

period of growth be multiplied by five, the result will in all probability not be far from the truth.

If we seek historical evidence, and from it attempt to discover the extreme limit of human life, we are puzzled at the differences in the ages said to have been attained. The longevity of the antediluvian patriarchs when contrasted with our modern experience seems incredible. When we look at an individual, say ninety years of age, taking even the most favorable specimen, a prolongation of life to ten times that number of years would appear too absurd even to dream about. There is certainly no physiological reason why the ages assigned to the patriarchs should not have been attained, and it is useless to discuss the subject, for we know very little of the conditions under which they lived. It is interesting to notice that after the Flood there was a gradual decrease in the duration of life. Abraham is recorded to have died at one hundred and seventy-five; Joshua, some five hundred years later, "waxed old and stricken in age" shortly before his death at one hundred and ten years; and his predecessor, Moses, to whom one hundred and twenty years are assigned, is believed to have estimated the life of man at threescore years and ten — a measure nowadays pretty generally accepted.

There is no reason for believing that the extreme limit of human life in the time of the Greeks and Romans differed materially from that which agrees with modern experience. Stories of the attainment of such ages as one hundred and twenty years and upward may be placed in the same category as the reputed longevity of Henry Jenkins, Thomas Parr, Lady Desmond, and a host of others. With regard to later times, such as the middle ages, there are no precise data upon which any statements can be based, but there is every reason to believe that the *average* duration of life was decidedly less than it is at present. The extreme limit, indeed, three or four centuries ago, would appear to have been much lower than in the nineteenth century. At the request of Mr. Thoms, Sir J. Duffus Hardy investigated the subject of the longevity of man in the thirteenth, fourteenth, fifteenth, and sixteenth centuries, and his researches led him to believe that persons seldom reached the age of eighty. He never met with a trustworthy record of a person who exceeded that age.

To bring the investigation down to quite recent times, I can not do better than utilize the researches of Dr. Humphry, Professor of Surgery at Cambridge. In 1886 he obtained particulars relating to fifty-two individuals then living and said to be one hundred years old and upward. The oldest among them claimed to be one hundred and eight, the next one hundred and six, while the average amounted to a little more than one hundred and two years. Many interesting facts connected with the habits and mode of life of these individuals were obtained by Dr. Humphry, and will be referred to in subsequent paragraphs.

A short account of the experience of a few life-assurance companies will conclude this part of my subject. Mr. Thoms tells us that down to 1872 the records of the companies showed that one death among the assured had occurred at one hundred and three, one in the one hundredth, and three in the ninety-ninth year. The experience of the National Debt Office, according to the same authority, gave two cases in which the evidence could be regarded as perfect; one of these died in the one hundred and second year, and the other had just completed that number. In the tables published by the Institute of Actuaries, and giving the mortality experience down to 1863 of twenty life-assurance companies, the highest age at death is recorded as ninety-nine; and I am informed by the secretary of the Edinburgh Life Office that from 1863 onward that age had not been exceeded in his experience. In the valuation schedules, which show the highest ages of existing lives in various offices, the ages range from ninety-two to ninety-five. It is true that one office which has a large business among the industrial classes reports lives at one hundred and three, and in one instance at one hundred and seven; but it must be remembered that among those classes the ages are not nearly so well authenticated as among those who assure for substantial sums. There is, moreover, another source of error connected with the valuation schedules. When a given life is not considered to be equal to the average, a certain number of years is added to the age, and the premium is charged at the age which results from this addition. It follows, therefore, that in some cases the ages given in the schedules are greater by some years than they really are.

Taking into consideration the facts thus rapidly passed under review, it must, I think, be admitted that the natural limit of

human existence is that assigned to it in the book of Ecclesiasticus, "The number of a man's days at the most are an hundred years" (chapter xviii. 9). In a very small number of cases this limit is exceeded, but only by a very few years. Mr. Thoms' investigations conclusively show that trustworthy evidence of one hundred and ten years having been reached is altogether absent. Future generations will be able to verify or reject statements in all alleged cases of longevity. It must be remembered that previous to the year 1836 there was no registration of births, but only of baptisms, and that the registers were kept in the churches, and contained only the names of those therein baptized.

Whatever number of years may be taken as representing the natural term of human life, whether threescore and ten or a century be regarded as such, we are confronted by the fact that only one-fourth of our population attains the former age, and that only about fifteen in one hundred thousand become centenarians. It is beyond the scope of this article to discuss the causes of premature mortality, but the conditions favorable to longevity, and the causes to which length of days has been assigned, are closely connected with its subject.

A capability of attaining old age is very often handed down from one generation to another, and heredity is probably the most powerful factor in connection with longevity. A necessary condition of reaching advanced age is the possession of sound bodily organs, and such an endowment is eminently capable of transmission. Instances of longevity characterizing several generations are frequently brought to notice. A recent and most interesting example of transmitted longevity is that of the veteran guardian of the public health, Sir Edwin Chadwick, who was entertained at a public dinner a few weeks ago on the occasion of his reaching his ninetieth year. He informed his entertainers that his father died at the age of eighty-four, one of his grandfathers at ninety-five, and that two more remote ancestors were centenarians.

It is difficult to estimate the influence of other contingencies which affect longevity. With regard to sex, Hufeland's opinion was that women were more likely than men to become old, but that instances of extreme longevity were more frequent among men. This opinion is to some extent borne out by Dr. Humph-

ry's statistics: of fifty-two centenarians, thirty-six were women. Marriage would appear to be conducive to longevity. A well-known French *savant,* Dr. Bertillon, states that a bachelor of twenty-five is not a better life than a married man of forty-five, and he attributes the difference in favor of married people to the fact that they take more care of themselves, and lead more regular lives than those who have no such tie. It must, however, be remembered that the mere fact of marrying indicates superior vitality and vigor, and the ranks of the unmarried are largely filled by the physically unfit.

In considering occupations as they are likely to affect longevity, those which obviously tend to shorten life need not be considered. With respect to the learned professions, it would appear that among the clergy the average of life is beyond that of any similar class. It is improbable that this average will be maintained for the future; the duties and anxieties imposed upon the clergy of the present generation place them in a very different position from that of their predecessors. Among lawyers there have been several eminent judges who attained a great age, and the rank and file of the profession are also characterized by a decided tendency to longevity. The medical profession supplies but few instances of extreme old age, and the average duration of life among its members is decidedly low, a fact which can be easily accounted for. Broken rest, hard work, anxieties, exposure to weather and to the risks of infection can not fail to exert an injurious influence upon health. No definite conclusions can be arrived at with regard to the average longevity of literary and scientific men, but it might be supposed that those among them who are not harassed by anxieties and enjoy fair health would probably reach old age. As a general rule, the duration of life is not shortened by literary pursuits. A man may worry himself to death over his books, or, when tired of them, may seek recreation in pursuits destructive to health; but application to literary work tends to produce cheerfulness, and to prolong rather than shorten the life even of an infirm man. In Prof. Humphry's "Report on Aged Persons," containing an account of eight hundred and twenty-four individuals of both sexes, and between the ages of eighty and one hundred, it is stated that forty-eight per cent. were poor, forty-two per cent. were in comfortable circumstances, and only ten per cent. were

described as being in affluent circumstances. Dr. Humphry points out that these ratios "must not be regarded as representing the relations of poverty and affluence to longevity, because, in the first place, the poor at all ages and in all districts bear a large proportion to the affluent; and, secondly, the returns are largely made from the lower and middle classes, and in many instances from the inmates of union work-houses, where a good number of aged people are found." It must also be noticed that the "past life-history" of these individuals showed that the greater proportion (fifty-five per cent.) "had lived in comfortable circumstances," and that only thirty-five per cent. had been poor.

Merely to enumerate the causes to which longevity has been attributed in attempting to account for individual cases would be a task of some magnitude; it will be sufficient to mention a few somewhat probable theories. Moderation in eating and drinking is often declared to be a cause of longevity, and the assertion is fully corroborated by Dr. Humphry's inquiries. Of his fifty-two centenarians, twelve were recorded as total abstainers from alcoholic drinks throughout life, or for long periods; twenty had taken very little alcohol; eight were reported as moderate in their use of it; and only three habitually indulged in it. It is quite true that a few persons who must be classified as drunkards live to be very old; but these are exceptions to the general rule, and such cases appear to be more frequent than they really are, because they are often brought to notice by those who find encouragement from such examples. The habit of temperance in food, good powers of digestion, and soundness of sleep are other main characteristics of most of those who attain advanced years, and may be regarded as causes of longevity. Not a few old persons are found on inquiry to take credit to themselves for their own condition, and to attribute it to some remarkable peculiarity in their habits or mode of life. It is said that Lord Mansfield, who reached the age of eighty-nine, was wont to inquire into the habits of life of all aged witnesses who appeared before him, and that only in one habit, namely, that of early rising, was there any general concurrence. Health is doubtless often promoted by early rising, but the habit is not necessarily conducive to longevity. It is, as Sir H. Holland points out, more probable that the vigor of the individuals main-

tains the habit than that the latter alone maintains the vitality.

If we pass from probable to improbable causes of longevity we are confronted by many extravagant assumptions. Thus, to take only a few examples, the immoderate use of sugar has been regarded not only as a panacea, but as decidedly conducive to length of days. Dr. Slare, a physician of the last century, has recorded the case of a centenarian who used to mix sugar with all his food, and the doctor himself was so convinced of the "balsamic virtue" of this substance that he adopted the practice, and boasted of his health and strength in his old age. Another member of the same profession used to take daily doses of tannin, under the impression that the tissues of the body would be thereby protected from decay. His life was protracted beyond the ordinary span, but it is questionable whether the tannin acted in the desired direction. Lord Combermere thought that his good health and advanced years were due, in part at least, to the fact that he always wore a tight belt round his waist. His lordship's appetite was doubtless thereby kept within bounds; we are further told that he was very moderate in the use of all fluids as drink. Cleanliness might be supposed to aid in prolonging life, yet a Mrs. Lewson, who died in the early part of this century, aged one hundred and six, must have been a singularly dirty person. We are told that instead of washing she smeared her face with lard, and asserted that "people who washed always caught cold." This lady, no doubt, was fully persuaded that she had discovered the universal medicine.

Many of the alchemists attributed the power of prolonging life to certain preparations of gold, probably under the idea that the permanence of the metal might be imparted to the human system. Descartes is said to have favored such opinions; he told Sir Kenelm Digby that, although he would not venture to promise immortality, he was certain that his life might be lengthened to the period of that enjoyed by the patriarchs. His plan, however, seems to have been the very rational and simple one of checking all excesses and enjoining punctual and frugal meals.

Having thus endeavored to show the extent to which human life may be prolonged, and having examined some of the causes or antecedents of longevity, the last subject for inquiry is the means by which it may be attained. Certain preliminary condi-

tions are obviously requisite; in the first place there must be a sound constitution derived from healthy ancestors, and in the second there must be a freedom from organic disease of important organs. Given an individual who has reached the grand climacteric, or threescore and ten, and in whom these two conditions are fulfilled, the means best adapted to maintain and prolong his life constitute the question to be solved. It has been said that "he who would long to be an old man must begin early to be one," but very few persons designedly take measures in early life in order that they may live longer than their fellows.

The whole term of life may be divided into the three main periods of growth and development, of maturity, and of decline. No hard and fast line can be drawn between these two latter phases of existence: the one should pass gradually into the other until the entire picture is changed. Diminished conservative power and the consequent triumph of disintegrating forces are the prominent features of the third period, which begins at different times in different individuals, its advent being mainly controlled by the general course of the preceding years. The "turning period," also known as the "climacteric" or "middle age," lies between forty-five and sixty; the period beyond may be considered as belonging to advanced life or old age. The majority of the changes characteristic of these last stages are easily recognizable. It is hardly necessary to mention the wrinkled skin, the furrowed face, the "crow's feet" beneath the eyes, the stooping gait, and the wasting of the frame. The senses, notably vision and hearing, become less acute; the power of digestion is lessened; the force of the heart is diminished; the lungs are less permeable; many of the air-cells lose their elasticity and merge into each other, so that there is less breathing surface as well as less power. Simultaneously with these changes the mind may present signs of enfeeblement; but in many instances its powers long remain in marked contrast with those of the body. One fact connected with advanced life is too often neglected. It should never be forgotten that while the "forces in use" at that period are easily exhausted, the "forces in reserve" are often so slight as to be unable to meet the smallest demand. In youth, the reserve powers are superabundant; in advanced life, they are reduced to a minimum, and in some instances are practically non-existent. The recognition of

this difference is an all-important guide in laying down rules for conduct in old age.

In order to prolong life and at the same time to enjoy it, occupation of some kind is absolutely necessary; it is a great mistake to suppose that idleness is conducive to longevity. It is at all times better to wear out than to rust out, and the latter process is apt to be speedily accomplished. Every one must have met with individuals who, while fully occupied till sixty or even seventy years of age, remained hale and strong, but aged with marvelous rapidity after relinquishing work, a change in their mental condition becoming especially prominent. There is an obvious lesson to be learned from such instances, but certain qualifications are necessary in order to apply it properly. With regard to mental activity, there is abundant evidence that the more the intellectual faculties are exercised the greater the probability of their lasting. They often become stronger after the vital force has passed its culminating point; and this retention of mental power is the true compensation for the decline in bodily strength. Did space permit, many illustrations could be adduced to show that the power of the mind can be preserved almost unimpaired to the most advanced age. Even memory, the failure of which is sometimes regarded as a necessary concomitant of old age, is not infrequently preserved almost up to the end of life. All persons of middle age should take special pains to keep the faculties and energies of the mind in a vigorous condition; they should not simply drift on in a haphazard fashion, but should seek and find pleasure in the attainment of definite objects. Even if the mind has not been especially cultivated, or received any decided bent, there is at the present day no lack of subjects on which it can be agreeably and profitably exercised. Many sciences which, twenty or thirty years ago, were accessible only to the few, and wore at best a somewhat uninviting garb, have been rendered not merely intelligible but even attractive to the many; and in the domain of general literature the difficulty of making a choice among the host of allurements is the only ground for complaint. To increase the taste for these and kindred subjects is worth a considerable effort, if such be necessary; but the appetite will generally come with the eating. The possession of some reasonable hobby which can be cultivated indoors is a great advantage in old age, and there are

many pursuits of this character besides those connected with literature and science. Talleyrand laid great stress on a knowledge of whist as indispensable to a happy old age, and doubtless to many old people that particular game affords not only recreation but a pleasant exercise to the mind. It is, however, an unworthy substitute for higher objects, and should be regarded only as an amusement and not as an occupation.

Whatever be the sphere of mental activity, no kind of strain must be put upon the mind by a person who has reached sixty-five or seventy years. The feeling that mental power is less than it once was not infrequently stimulates a man to increased exertions which may provoke structural changes in the brain, and will certainly accelerate the progress of any that may exist in that organ. When a man finds that a great effort is required to accomplish any mental task that was once easy, he should desist from the attempt, and regulate his work according to his power. With this limitation, it may be taken for granted that the mental faculties will be far better preserved by their exercise than by their disuse.

Somewhat different advice must be given with regard to bodily exercises in their reference to longevity. Exercise is essential to the preservation of health; inactivity is a potent cause of wasting and degeneration. The vigor and equality of the circulation, the functions of the skin, and the aeration of the blood, are all promoted by muscular activity, which thus keeps up a proper balance and relation between the important organs of the body. In youth, the vigor of the system is often so great that if one organ be sluggish another part will make amends for the deficiency by acting vicariously, and without any consequent damage to itself. In old age, the tasks can not be thus shifted from one organ to another; the work allotted to each sufficiently taxes its strength, and vicarious action can not be performed without mischief. Hence the importance of maintaining, as far as possible, the equable action of all the bodily organs, so that the share of the vital processes assigned to each shall be properly accomplished. For this reason exercise is an important part of the conduct of life in old age; but discretion is absolutely necessary. An old man should discover by experience how much exercise he can take without exhausting his powers, and should be careful never to exceed the limit. Old persons are apt to

forget that their staying powers are much less than they once were, and that, while a walk of two or three miles may prove easy and pleasurable, the addition of a return journey of similar length will seriously overtax the strength. Above all things, sudden and rapid exertion should be scrupulously avoided by persons of advanced age. The machine which might go on working for years at a gentle pace often breaks down altogether when its movements are suddenly accelerated. These cautions may appear superfluous, but instances in which their disregard is followed by very serious consequences are by no means infrequent.

No fixed rule can be laid down as to the kind of exercise most suitable for advanced age. Much must depend upon individual circumstances and peculiarities; but walking in the open air should always be kept up and practiced daily, except in unfavorable weather. Walking is a natural form of exercise and subserves many important purposes: not a few old people owe the maintenance of their health and vigor to their daily "constitutional." Riding is an excellent form of exercise, but available only by a few; the habit, if acquired in early life, should be kept up as long as possible, subject to the caution already given as to violent exercise. Old persons of both sexes fond of gardening, and so situated that they may gratify their tastes, are much to be envied. Body and mind are alike exercised by what Lord Bacon justly termed "the purest of human pleasures." Dr. Parkes goes so far as to say that light garden or agricultural work is a very good exercise for men past seventy: "It calls into play the muscles of the abdomen and back, which in old men are often but little used, and the work is so varied that no muscle is kept long in action." A few remarks must be made, in conclusion, with regard to a new form of exercise sometimes indulged in even by elderly men. I allude to so-called "tricycling." Exhilarating and pleasant as it may be to glide over the ground with comparatively little effort, the exercise is fraught with danger for men who have passed the grand climacteric. The temptation to make a spurt must be often irresistible; hills must be encountered, some perhaps so smooth and gradual as to require no special exertion, none, at least, that is noticed in the triumph of surmounting them. Now, if the heart and lungs be perfectly sound, such exercises may be prac-

ticed for some time with *apparent* impunity; but if (as is very likely to be the case) these organs be not quite structurally perfect, even the slightest changes will, under such excitement, rapidly progress and lead to very serious results. Exercise unsuited to the state of the system will assuredly not tend to the prolongation of life.

With regard to food, we find from Dr. Humphry's report that ninety per cent. of the aged persons were either "moderate" or "small" eaters, and such moderation is quite in accord with the teachings of physiology. In old age the changes in the bodily tissues gradually become less and less active, and less food is required to make up for the daily waste. The appetite and the power of digestion are correspondingly diminished, and although for the attainment of a great age a considerable amount of digestive power is absolutely necessary, its perfection, when exercised upon proper articles of diet, is the most important characteristic. Indulgence in the pleasures of the table is one of the common errors of advanced life, and is not infrequent in persons who, up to that period, were moderate or even small eaters. Luxuries in the way of food are apt to be regarded as rewards that have been fully earned by a life of labor, and may, therefore, be lawfully enjoyed. Hence arise many of the evils and troubles of old age, and notably indigestion and gouty symptoms in various forms, besides mental discomfort. No hard and fast rules can be laid down, but strict moderation should be the guiding maxim. The diet suitable for most aged persons is that which contains much nutritive material in a small bulk, and its quantity should be in proportion to the appetite and power of digestion. Animal food, well cooked, should be taken sparingly and not more often than twice a day, except under special circumstances. Dr. Parkes advocates rice as a partial substitute for meat when the latter is found to disagree with old persons. "Its starch-grains are very digestible, and it supplies nitrogen in moderate amount, well fitted to the worn and slowly repaired tissues of the aged." Its bulk, however, is sometimes a disadvantage; in small quantities it is a valuable addition to milk and to stewed fruits.

The amount of food taken should be divided between three or four meals at fairly regular intervals. A sense of fullness or oppression after eating ought not to be disregarded. It indicates

that the food taken has been either too abundant or of improper quality. For many elderly people the most suitable time for the principal meal is between 1 and 2 P. M. As the day advances the digestive powers become less, and even a moderately substantial meal taken in the evening may seriously overtask them. Undigested food is a potent cause of disturbed sleep, an evil often very troublesome to old people, and one which ought to be carefully guarded against.

It is an easier task to lay down rules with regard to the use of alcoholic liquors by elderly people. The Collective Investigation Committee of the British Medical Association has lately issued a "Report on the Connection of Disease with Habits of Intemperance," and two at least of the conclusions arrived at are worth quoting: "Habitual indulgence in alcoholic liquors, beyond the most moderate amount, has a distinct tendency to shorten life, the average shortening being roughly proportional to the degree of indulgence. Total abstinence and habitual temperance augment considerably the chance of death from old age or natural decay, without special pathological lesion." Subject, however, to a few exceptions, it is not advisable that a man sixty-five or seventy years of age, who has taken alcohol in moderation all his life, should suddenly become an abstainer. Old age cannot readily accommodate itself to changes of any kind, and to many old people a little good wine with their meals is a source of great comfort. To quote again from Ecclesiasticus, "Wine is as good as life to a man, if it be drunk moderately, for it was made to make men glad." Elderly persons, particularly at the close of the day, often find that their nervous energy is exhausted, and require a little stimulant to induce them to take a necessary supply of proper nourishment, and perhaps to aid the digestive powers to convert their food to a useful purpose. In the debility of old age, and especially when sleeplessness is accompanied by slow and imperfect digestion, a small quantity of a generous and potent wine, containing much ether, often does good service. Even a little beer improves digestion in some old people; others find that spirits, largely diluted, fulfil the same purpose. Individual peculiarities must be allowed for; the only general rule is that which prescribes strict moderation.

It is not to be inferred from the hints given in the preceding paragraphs that the preservation of health should be the pre-

dominant thought in the minds of elderly persons who desire that their lives should be prolonged. To be always guarding against disease, and to live in a state of constant fear and watchfulness, would make existence miserable and hasten the progress of decay. Selfish and undue solicitude with regard to health not only fails to attain its object, but is apt to induce that diseased condition of mind known as hypochondriasis ("the blues"), the victims of which are always a burden and a nuisance, if not to themselves, at least to all connected with them. Addison, in the *Spectator,* after describing the valetudinarian who constantly weighed himself and his food, and yet became sick and languishing, aptly remarks, "A continual anxiety for life vitiates all the relishes of it, and casts a gloom over the whole face of nature, as it is impossible that we should take delight in anything that we are every moment afraid of losing."

Sleep is closely connected with the question of diet; "good sleeping" was a noticeable feature in the large majority of Dr. Humphry's cases. Sound, refreshing sleep is of the utmost consequence to the health of the body, and no substitute can be found for it as a restorer of vital energy. Sleeplessness is, however, often a source of great trouble to elderly people, and one which is not easily relieved. Narcotic remedies are generally mischievous; their first effects may be pleasant, but the habit of depending upon them rapidly grows until they become indispensable. When this stage has been reached, the sufferer is in a far worse plight than before. In all cases the endeavor should be made to discover whether the sleeplessness be due to any removable cause — such as indigestion, cold, want of exercise, and the like. In regard to sleeping in the daytime, there is something to be said both for and against that practice. A nap of "forty winks" in the afternoon enables many aged people to get through the rest of the day in comfort, whereas they feel tired and weak when deprived of this refreshment. If they rest well at night there can be no objection to the afternoon nap; but if sleeplessness be complained of, the latter should be discontinued for a time. Most old people find that a reclining posture, with the feet and legs raised, is better than the horizontal position for the afternoon nap. Digestion proceeds with more ease than when the body is recumbent.

Warmth is very important for the aged; exposure to chills should be scrupulously avoided. Bronchitis is the malady most to be feared, and its attacks are very easily provoked. Many old people suffer from more or less cough during the winter months, and this symptom may recur year after year, and be almost unheeded. At last, perhaps a few minutes' exposure to a cold wind increases the irritation in the lungs, the cough becomes worse, and the difficulty of breathing increases until suffocation terminates in death. To obviate such risk the skin should be carefully protected by warm flannel clothes, the out-door thermometer should be noticed and winter garments should always be at hand. In cold weather the lungs should be protected by breathing through the nose as much as possible, and by wearing a light woolen or silken muffler over the mouth. The temperature of the sitting and bed-rooms is another point which requires attention. Some old people pride themselves on never requiring a fire in their bed-rooms. It is, however, a risky practice to exchange a temperature of 65° to 70° for one fifteen or twenty degrees lower. As a general rule, for persons sixty-five years of age and upward, the temperature of the bed-room should not be below 60°, and when there are any symptoms of bronchitis it should be raised from five to ten degrees higher.

Careful cleansing of the skin is the last point which needs to be mentioned in an article like the present. Attention to cleanliness is decidedly conducive to longevity, and we may congratulate ourselves on the general improvement in our habits in this respect. Frequent washing with warm water is very advantageous for old people, in whom the skin is only too apt to become hard and dry; and the benefit will be increased if the ablutions be succeeded by friction with coarse flannel or linen gloves, or with a flesh-brush. Every part of the skin should be thus washed and rubbed daily. The friction removes worn-out particles of the skin, and the exercise promotes warmth and excites perspiration. Too much attention can hardly be paid to the state of the skin; the comfort of the aged is greatly dependent upon the proper discharge of its functions.

Such, then, are the principal measures by which life may be prolonged and health maintained down to the closing scene. It remains to be seen whether, as a result of progress of knowledge and civilization, life will ever be protracted beyond the limit

assigned to it in a preceding paragraph. There is no doubt that the *average duration* of human life is capable of very great extension, and that the same causes which serve to prolong life materially contribute toward the happiness of mankind. The experience of the last few decades abundantly testifies to the marked improvement which has taken place in the public health. Statistics show that at the end of the septennial period, 1881–'87, 400,000 persons were alive in England and Wales whose death would have taken place had the mortality been in the same proportion as during the previous decade. It may be reasonably expected that as time goes on there will be an increase in the proportion of centenarians to the population as a whole.

The question whether long life is, after all, desirable does not admit of any general answer. Much depends upon the previous history of the individual, and his bodily and mental condition. The last stages of a well spent life may be the happiest, the shuffling-off of the mortal coil, though calmly expected, need not be wished for. The picture afforded by cheerful and mellow old age is a lesson to younger generations. Elderly people may, if they choose, become centers of improving and refining influence. On the other hand, old age can not be regarded as a blessing when it is accompanied by profound decrepitude and disorder of mind and body. Senile dementia, or second childishness, is, of all conditions, perhaps the most miserable, though not so painful to the sufferer as to those who surround him. Its advent may be accelerated by ignorance and neglect, and almost assuredly retarded or prevented by such simple measures as have been suggested. No one who has had opportunities of studying old people can shut his eyes to the fact that many of the incapabilities of age may be prevented by attention to a few simple rules, the observance of which will not only prolong life and make it happier and more comfortable, but will reduce to a minimum the period of decrepitude. Old age may be an incurable disease, admitting of but one termination, but the manner of that end, and the condition which precedes it, are, though not altogether, certainly to a very great extent, within our own power.

THE FIGHT AGAINST CONSUMPTION.

By NEWELL DUNBAR.

THE human race is evidently destined for great things. Life nowadays is indeed worth living; intense — quick. We wake up every morning to find a fresh domain come under man's hand. The remoteness of earth's four corners he is learning to defy with electric locomotives and automobiles. Not content with the ocean's surface, in his submarine boat, fish-like, he now navigates its depths. The air, too, that long baffled him, at last he lords. Nothing is too distant or too near, too large or too small, too high or too low to escape him. Mysteries, even the existence of which have been unsuspected in cases through the ages (bacteria, Röntgen rays, Becquerel rays, radium, etc.), now yield up their secrets. Some day man will find out that life can really be lived on a basis of love instead of hate, establish a rational way of distributing wealth, and conclude that settling disputes by fighting does not pay. Death he may not hope to evade. But his old foe, Disease, it looks as if he might in time seriously worry, if not in some of its forms practically quell.

On the principle of choosing a representative that *represents,* let us take Consumption and see how man stands to-day toward that king of maladies.

That consumption is indeed the worst ailment that preys upon mankind the following facts will show: It flourishes throughout the world, is always at work, and it has ravaged the race for thousands of years. In severe or mild form it affects at least one-half of the earth's inhabitants, causing fully one-seventh of the total number of deaths — between the ages of fifteen and forty-five about one-third. Between thirty-five and forty-four, when the world's productive workers are at their best and so can least be spared, one person dies from it in every four. It ends far more lives than all other forms of infectious diseases combined (only pneumonia making any approach to it in de-

structiveness). Leprosy, the dread scourge of the East, is a hundred-fold less contagious, as to contract it requires much more intimate intercourse (indeed consumption does not need any). In the United States it occasions one-tenth of the deaths from all causes, 160,000 succumbing to its insidious undermining every year. In the single state of California — which, by the way, is called the consumptives' paradise — it is said annually to destroy more lives than yellow fever has done in the whole United States for the last twenty-two years. Its victims every two years in New York city outnumber those of small-pox in the whole country since our government began. The deaths annually from it in any town of five thousand inhabitants in the country exceed those from Asiatic cholera throughout the United States for over a quarter of a century. The increase in the number of its victims more than keeps pace with the increase of the population. (Owing, doubtless, to the fact of the present tendency to collect in cities, where people are brought close together and opportunities are numerous for contracting disease. Among the children, especially, in cities the mortality from it is appalling, and still grows.) In the late Boer war, severe as was Great Britain's loss by the bullet, consumption cost her eighteen times as many lives. Indeed, till comparatively lately a physician's verdict of consumption carried with it simply doom to inevitable and probably near death, to which the invalid and his friends had nothing to do but resign themselves with what grace they might. Facts as gruesome as these may well give even the most thoughtless pause!

No disease can be understood till we know its cause. We now see that for centuries the learned even, however from time to time they may have changed their views of what produces certain disorders — or at least expressed them differently — when they did not cover up utter ignorance in a mere wrapper of words, held opinions that were false. It was one of the crowning glories of the nineteenth century that toward its close it scientifically established the cause of consumption, pneumonia, diphtheria, typhoid fever, scarlatina, small-pox, cholera, etc.— all germ diseases, as they are called.* (Among them will be noticed

* No doubt many readers have often smiled at some of the ludicrous expressions that came to the surface in the "germ" ferment of the last thirty years; e. g., the germ of laziness, the germ of love, the golf germ, etc.

some of mankind's direst foes.) The list gradually grew, and there is good hope in the future it will reach still further. The production of diseases by germs must be classed among mankind's really great discoveries.*

The germ-production of disease, or the germ theory of disease (as it is called) — briefly, and without going too much into detail — is as follows: In the last quarter of the nineteenth century it was discovered that the earth, air, and water are filled with countless numbers of living things, far too small to be visible to the naked eye, called germs, microbes, or micro-organisms. One important group of these belongs to the microscopic plants called bacteria, which live mostly on dead organic matter — that is, on what has once formed some part of a living being. In doing this they release the oxygen, hydrogen, and nitrogen of which all living things are largely composed, and of which, the supply in nature being limited, the quantities used in one form must be in some way restored to the general fund for use again, or the cycle of life would cease. So far as bacteria perform this office merely their work is beneficent. They are most lively multipliers, and each germ is a little chemical laboratory, absorbing the organic matter it feeds upon and resolving it into new compounds. Some of these go to maintain and build up the germ's own body, while others are given off into its surroundings. A few bacteria choose to live in the bodies of men. Here they feed on the tissues, and by setting free and returning to them certain poisons existing in the blood produce those disturbances, and changes of structure, called disease. The diseases caused by the growth of such germs in the body are called infectious. The germs are given off from the body, and in some way (as by movement through the air) reach and find lodgment in other persons, in whom they produce similar disease. It is not the disease itself, but the germ which causes it, that is transmitted or is "catching." The germ theory of disease holds (and it has proved its point) that germ diseases are never self-produced in the body, but are always caused by minute beings that propagate themselves, and enter the body from without — beings

* It had been held by many since about 1683 that epilepsy, gout, typhus fever, measles, small-pox, malaria, etc., were caused by minute living animals or plants in the body; but, as these were supposed to be "spontaneously generated," it came to the same thing as the disease *breaking out of itself*. The matter was not cleared up till 1876.

that can be seen, handled, and killed. Here was taken an immense stride!

The germ that causes man's arch-scourge, consumption or tuberculosis (to use the scientific name), is called the tubercle bacillus, and was discovered by the famous German physician, Robert Koch, in 1882. It, and it alone — it is now known — produces consumption. Without its entrance in a living condition into a human body, consumption cannot develop there; without its transmission in some way from the sick to the well, tuberculosis cannot spread. The whole secret of the attack, prevention, and cure of consumption lies in the study of the tubercle bacillus.

The tubercle bacillus is not as is sometimes thought a minute animal, but a microscopic *plant,* thriving best on animal tissue, and then only at temperatures about that of the normal human body. It is so small that a group consisting of thousands of them is imperceptible to the naked eye. It cannot move about nor grow without moisture. The bodies of a few warm-blooded animals also harbor it. It has been cultivated artificially in laboratories, and more, fortunately, is known of its peculiarities than of those of almost any other germ. Heat, sunlight, and many disinfectants readily kill it, but in a dried state it will remain alive for weeks. On once gaining lodgment in a body favorable to its growth it multiplies slowly, dividing and subdividing. As it feeds on the tissues, setting free and returning to them poisons in the blood, it stimulates the cells of the body to produce little knob-shaped masses of new tissue called tubercles. The tubercle bacillus may lodge in almost any part of the body, and cause tubercles there; it sometimes does so, for instance, in the intestinal canal. But tubercles are by far most common on the lungs. Tubercles as a rule soon die and break up. Then (if in a part of the body where this is possible, as in the lungs) the waste material, often bearing thousands of living germs, is cast off from the body. In consumption this dangerous dead matter is thrown off in the sputum or spittle.

We are now in a position to see the following facts: Consumption is "catching," like measles, whooping-cough, or diphtheria. The only way we can contract it is by getting into our bodies tubercle bacilli. These may come from diseased men or animals, the former source of danger being by far the greater. (Among

animals practically the only risk is in cattle, from the use of diseased meat or unboiled milk.) From men, however, there is no danger — even to constant attendants, or in the closest intimacy (as that of husband and wife) — of getting bacilli in the breath, which used to be thought so deadly. Contact, too, with any healthy clean part of a consumptive's body is perfectly safe. In what consumptives cough up and spit out, in the phlegm (or sputum, as it is called), is where the danger lies. A person moderately far gone in the disease expectorates, it has been calculated, from one million to five million tubercle bacilli in twenty-four hours. *Moist* sputum as a rule is harmless — unless it be directly transmitted to the well person. (This may happen in violent coughing, sneezing, etc., by unwashed dishes or cooking utensils, from soiled hands, in kissing, caressing, or in some such way.) *Dried* sputum — and here is the point, it cannot be made too plain, nor too much dwelt upon — is the great source of contagion in consumption. In one way and another (as by being rubbed against, or trodden upon) it becomes pulverized into dust, which floats around in the air and is thence breathed in. This dust is found in consumptives' rooms (on floors, walls, bedding, handkerchiefs, towels, the patient's person, etc.); is blown about by the wind in the streets; enters schoolrooms, trolley and steam cars, cabs, theaters, factories, workshops, churches, is found on the cup at drinking fountains, etc. Dried sputum has been for untold years the hidden cause from which a large part of the human race has prematurely perished. It has always been, and is to-day, the source of the spread of consumption. And upon the thorough destruction (by fire) of consumptives' spittle before it dries, or its being rendered harmless (by treating it with some disinfectant, as a solution of corrosive sublimate not less in strength than one to five hundred) depends the arrest in large measure of the spread of this dread disease.

The reason that — with all this exposure — everybody does not get consumption is that, while we are in good health, nature is able to overcome the germs. If they invade our bodies they are cast out again — by secretion, or through the mouth — before effecting lodgment. Should they even enter the blood the white corpuscles there kill and dispose of them. Most of us inhale many of these germs without being harmed. Indeed many persons have had and got rid of small pulmonary tubercles

without ever knowing it. Their strength and general health were such that they could overcome even these. It is when we are run down, or weakened by other disease, or there is an irritation or abrasion of the breathing organs (as from a cold), that the inhaled bacilli find lodgment, and consumption begins. There is danger, too, in the *number* of the germs that assail us: a *few* we may overpower; *many* are likely to overpower us. On an average, it is calculated, it takes five implantings of the bacilli to give consumption.

One thing clearly shown by the discovery of the true cause of tuberculosis is that consumption is not hereditary (as, for instance, are gout, insanity, and various nervous complaints handed down from parent to offspring). The reason that it was so long held to be so is, that when once it had attacked one member of a family it generally sooner or later appeared in another. But this is now seen to have been due to the house being infected with the germs. Some persons are more sensitive to the influence of bacteria than are others, and the same person is more so at one time than at another. This *susceptibility,* in the case of consumption, is undoubtedly hereditary. It is not, however, the *disease,* or the certainty of developing it, that comes into the world with the successive children of certain families, but merely this *aptitude to contract* the disease if external conditions should favor. Without the absorption in some way of tubercle bacilli — no matter how great the aptitude — consumption is impossible. The members of families having this hereditary tendency should strive, in all their occupations, amusements, food, exercise, whole manner of living, indeed, to make their life as healthy and themselves as vigorous as possible. They should be particularly careful to avoid places and occupations in which the, to them, especially deadly tubercle bacillus lurks, in the air or otherwise.

Many consumptives mingle for purposes of business or pleasure, often for years, with their fellows. Every such invalid, unless he be intelligently careful in his habits, is a source of constant danger to all around him. Consumptives must be invariably taught never to spit on the floor or in the street (at best a disgusting habit), nor on handkerchiefs (which may do mischief before they are disinfected and washed). They should always expectorate into a proper receptacle, which may be fre-

quently and thoroughly cleansed. The streets of some cities provide elevated self-cleansing spittoons for public use. A pocket flask is convenient as well as safe when the patient is out of doors, or at his business. At home he may use a water-proof paper cup, books made of old newspaper, moist rags, or Japanese paper napkins, which, with their contents, can be burned. Those too ill to care for themselves in this respect should be scrupulously cared for by others. Even the invalid's own chances of recovery are thus improved, as he is no longer running the risk of taking a second time into himself material he had once cast out. Every consumptive should sleep by himself, and in a separate room.

As a protection against consumption and other diseases, in cities the streets ought always to be sprinkled before cleaning; this prevents the dust containing germs from rising. In our houses, in cleaning the dust should not be merely stirred up and left to settle in a different (and probably worse) place. It must be removed with a damp cloth or chamois, and this should afterwards be washed out, and the water allowed to run off. Sweeping is best done with moist tea-leaves. Certain changes too in the usual style of furnishing would be for the better. Thick-piled carpets, for instance, might be replaced by rugs that can easily and often be taken outside and thoroughly cleansed. Heavy hangings exclude the sunlight, shut the bad air in and the fresh air out, and catch and hold dust and germs that otherwise would be expelled. Rough fabrics in upholstering might profitably be disused. Hotel rooms, particularly after occupation by a consumptive, all means of public conveyance, etc., should be scrupulously cleansed.

An organized movement to arrest the spread of consumption has been going on now for several years throughout the United States. Ordinances were passed relative to spitting in public places, and efforts made to extend a general knowledge in regard to consumption as widely as possible among the public. The state of Massachusetts, which usually manages to be to the fore in matters of reform, established the first State sanatorium at Rutland, in 1898. In 1903 was formed the Boston Association for the Relief and Control of Tuberculosis. New York city has the honor of leading the world in thorough organization against consumption. Officially and without charge, it informs all applicants whether their sputum contains bacilli. Those affected

are thus enabled to know the fact in time, and — which means everything in consumption — to grapple with the disease at its very start. New York State is soon to have a sanatorium to cost a half-million of dollars, and New Jersey is planning one almost as large. Compulsory report and official registration (as in the cases of scarlet fever and diphtheria) now exists throughout New England, New York, New Jersey, Michigan, and the District of Columbia (thirty-eight per cent. of the whole population of the country), and is growing. Without being intrusive the authorities generally are beginning to insist upon knowing where cases are housed, from time to time by inspection or report what progress is made, etc. Health boards have taken measures to avert the dangers from diseased cattle.

As a result of this movement a general diminution in the number of cases is apparent. In New York city since 1881 the mortality from consumption has lessened forty per cent., and by 1906 Dr. Biggs, the able physician of the New York board of health, hopes the number of deaths from tuberculosis will be 3,000 less annually than formerly. Abroad the success from similar efforts has been marked. England, which now has the greatest number of special hospitals for consumptives of any country in the world, has won the most brilliant victory. In Prussia from 1889 to 1897 the number of deaths from tuberculosis was 184,000 less than what was to be expected from the average of the years just preceding. Pasteur, the great French chemist, said: "It is in the power of man to cause all parasitic diseases to disappear from the earth." Koch says: "All that is necessary is to go on . . . If we aim . . . at striking the evil at its root, then the battle against tuberculosis, which has been so energetically begun, cannot fail to have a victorious issue."

As to cure: It is now generally admitted that consumption — especially if not accompanied by any complaint of the heart, kidneys, or digestive organs, and the blood-making apparatus is in good order — is, in its early stages at least, curable. In no stage can it be cured by drugs; still less by any widely advertised "sure cure for consumption." (Nostrums of this sort may almost invariably be set down as money-getting devices of the conscienceless — to be shunned as death-traps.) Its successful treatment is wholly "natural," and consists of building up the

patient's general health, and supplying him with the elements needed, so that his own constitution can effect the cure. It is one of the beneficent provisions of nature that, when tubercle bacilli find lodgment in a body, the body cells often build a thick enclosing wall round the part affected, shutting it off from the rest of the body. If well nourished by food, and supplied with abundant fresh air, the body cells are often able for years thus successfully to resist the encroachment of the bacilli, to hold them at bay, and to give the affected person usefulness in and the enjoyment of his life.* Successful treatment of consumption builds upon this fact. Its main prescriptions are an abundance of fresh air and plenty of food.

The patient, if possible, "drops everything" and becomes an inmate of an open-air sanatorium. Here (except in stormy weather) he literally lives in the open air, summer or winter, day and night. At all seasons he sleeps either under the open sky, or in a tent open at the top and sides, on an open veranda, or, if (under stress of foul weather) in the house, with the windows at all seasons wide open. The oxygen effects the cure. Cold weather does not interfere with his way of life; though, of course, in winter and at all times he is comfortably clad. He takes *al fresco* sun-baths. Six plain but substantial meals a day are his diet, and between meals he has been known to swallow in the twenty-four hours as many as thirty-six raw eggs. His meals consist of plenty of meat (not shunning the fat), oatmeal porridge, dry toast and crusts of bread well chewed, eggs, abundant milk, etc. It is found that as a rule it is best for him not to take anything like violent exercise. (The reason of this is that the labored breathing it produces interferes with the proper healing of the injured lung. It causes to grow a larger proportion of scar tissue — tissue filling up and growing over the cavities made in the lung by the disease — and this tissue is useless for breathing purposes. The more the patient has of it after recovery the more imperfect his cure. Indeed during treat-

* This fact undoubtedly accounts for the persons the writer remembers to have seen — before the tubercle bacillus was heard of — in various Rocky-mountain localities. They had been forced by consumption to remove, on a chance of improvement, to the West — some of them so far gone when they started that nobody supposed they would ever live to reach the Rockies. Yet, as soon as they arrived there and entered upon an open-air life, they had begun to recover and build up, and when seen by the writer were apparently as hardy as men could be. Many of them however did not dare leave their adopted home.

ment labored respiration is often made impossible by applying strips of adhesive plaster to the outside skin over the affected lung, and by injecting into the latter nitrogen gas, which hinders its action.) The main remedies, air and food, are supplemented by complete rest of body and mind. There are conversation, reading (out-of-doors), and amusements (such as cards, checkers, golf, croquet, etc.).

Absence of fever hastens the cure. It is the fever that wears the patient out. The "night sweats" that used popularly to be thought so weakening are now deemed to be, however uncomfortable, beneficial. The water and small quantities of salt lost by them are easily replaced; while all else they carry off, the system is better without. Even hemorrhages — so revolutionized is the whole subject — are nowadays not dreaded as they used to be. They occur on the expulsion of the broken-up tubercles; an opening is then made, at the place where a tubercle disintegrates, in the blood tubes and blood escapes. One result, however, of this is that the blood flows over the diseased part, kills the germs it encounters (an effect of blood, particularly of shed blood, upon tubercle bacilli), and knits the wound together. Any weakening effect the loss of blood may have is compensated by the abundant nourishment of the treatment. Of the cough, the worst effect is that sometimes it keeps the patient awake; often, however, sleep is obtained by lying on the well side. The patient stays in the sanatorium six months, or better a year. On coming out he is very careful for two years; and then, if there has been no relapse, he considers himself cured.

The great majority, however, of patients must be treated at home. Here they will follow as nearly as possible the same course as if in a sanatorium. And if (as should be the case) the other members of the family can put up with the "queer ways," do not mind the inconvenience of the special diet and additional meals, and the patient himself is naturally independent, endowed with will, and careless of the "talk" of "friends" and neighbors, there is no reason in the world why the home treatment should not — on the contrary there is abundant reason why it should — be equally successful with that at the best sanatorium in the land. One hears of effective home treatment. The patient treated at home should invariably be under a physician's supervision.

It must still, however, be confessed that, with our present knowledge, advanced consumption is incurable. And, in *all* cases, a complete restoration to the condition the person was in before seizure is impossible. A portion of the lung is gone. A number of air cells have been obliterated (their place being taken by fibrous scar tissue, like what appears on the face after small-pox). The case, however, is worse than small-pox, as vital tissue has been destroyed, and a permanent disability incurred. The loss of the aërating cells from the lung must ever after cause the body to receive an insufficient supply of oxygen. The person for the rest of his life will be short of breath.

There are hopeful statistics of the success of this treatment. In 1901 Koch stated the German sanatoria — which receive only patients in the early stages — were discharging twenty per cent. cured; he felt sure, however, by proper management the percentage could be raised to fifty — perhaps still higher. In the cold climates sanatoria receiving practically the same class of patients cure, it has been stated, from seventy to seventy-five per cent. For twelve years the sanatorium for women at Sharon, Mass., has been highly successful. Recently sanatoria in the West and Southwest have successfully treated some cases even in the third or worst stage of consumption. In some respects as good an institution as we can find to take figures from is the United States sanatorium for consumptive sailors at Fort Stanton, New Mexico; because, though it admits cases even in the most advanced stages, we may feel absolutely sure of the correctness of the facts given. Its report in 1903 shows that, in the three and a half years of its existence — exclusive of patients still under treatment with as yet undecided results — it had cured nearly fifty-one per cent. of its patients in the first stage; nearly nine per cent. of those in the second and third stages (the report furnishes no means of telling how many of these belonged in the second); and over fifteen per cent. of all three classes in a lump. Consumption is no longer the hopeless malady it was once deemed. A long, bright, and useful life may still be his who has felt upon him the finger of this dire disease, if he understands it in time, and by the proper means patiently and energetically combats it.

One of the most brilliant achievements of the nineteenth century — which made more progress in medicine and surgery than

had been made during the previous two thousand years — was the germ theory of disease. Though this has not yet brought complete mastery over Consumption, the facts, in regard to the most fatal malady known to the race, that we have learned its cause, know how to prevent its spread, and in its early stages can cure, well deserve a place in any discriminating list of modern great discoveries.

MALARIA AND MOSQUITOES.*

By GEORGE M. STERNBERG, M. D., LL.D.

IN my address as president of the Biological Society, in 1896, the subject chosen was "The malarial parasite and other pathogenic protozoa." This address was published in March, 1897, in the Popular Science Monthly, and I must refer you to this illustrated paper for a detailed account of the morphological characters of the malarial parasite. It is my intention at the present time to speak of "malaria" in a more general way, and of the recent experimental evidence in support of Manson's suggestion, first made in 1894, that the mosquito serves as an intermediate host for the parasite. The discovery of this parasite may justly be considered one of the greatest achievements of scientific research during the nineteenth century. Twenty-five years ago the best-informed physicians entertained erroneous ideas with reference to the nature of malaria and the etiology of the malarial fevers. Observation had taught them that there was something in the air in the vicinity of marshes in tropical regions, and during the summer and autumn in semi-tropical and temperate regions, which gave rise to periodic fevers in those exposed in such localities, and the usual inference was that this something was of gaseous form — that it was a special kind of bad air generated in swampy localities under favorable meteorological conditions. It was recognized at the same time that there are other kinds of bad air, such as the offensive emanations from sewers and the products of respiration of man and animals, but the term malaria was reserved especially for the kind of bad air which was supposed to give rise to the so-called malarial fevers. In the light of our present knowledge it is evident that this term is a misnomer. There

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is no good reason for believing that the air of swamps is any more deleterious to those who breathe it than the air of the sea-coast or that in the vicinity of inland lakes and ponds. Moreover, the stagnant pools which are covered with a "green scum," and from which bubbles of gas are given off, have lost all terrors for the well-informed man, except in so far as they serve as breeding places for mosquitoes of the genus *Anopheles*. The green scum is made up of harmless algæ, such as Spirogyra, Zygnema, Protococcus, Euglena, etc.; and the gas which is given off from the mud at the bottom of such stagnant pools is for the most part a well-known and comparatively harmless compound of hydrogen and carbon — methane or "marsh gas." In short, we now know that the air in the vicinity of marshes is not deleterious because of any special kind of bad air present in such localities, but because it contains mosquitoes infected with a parasite known to be the specific cause of the so-called malarial fevers. This parasite was discovered in the blood of patients suffering from intermittent fevers by Laveran, a surgeon in the French army, whose investigations were conducted in Algiers. This famous discovery was made toward the end of the year 1880, but it was several years later before the profession generally began to attach much importance to the alleged discovery. It was first confirmed by Richard in 1882; then by the Italian investigators, Marchiafava, Celli, Golgi, and Bignami; by Councilman, Osler, and Thayer, in this country, and by many other competent observers in various parts of the world. The Italian investigators named not only confirmed the presence of the parasite discovered by Laveran in the blood of those suffering from malarial fevers, but they demonstrated its etiological rôle by inoculation experiments and added greatly to our knowledge of its life history (1883-1898). The fact that the life history of the parasite includes a period of existence in the body of the mosquito as an intermediate host has recently been demonstrated by the English army surgeons Manson and Ross, and confirmed by numerous observers, including the famous German bacteriologist, Koch.

The discoveries referred to, as is usual, have had to withstand the criticism of conservative physicians, who, having adopted the prevailing theories with reference to the etiology of periodic fevers, were naturally skeptical as to the reliability of the obser-

vations made by Laveran and those who claimed to have confirmed his discovery. The first contention was that the bodies described as present in the blood were not parasites, but deformed blood corpuscles. This objection was soon set at rest by the demonstration, repeatedly made, that the intra-corpuscular forms underwent distinct amœboid movements. No one witnessing these movements could doubt that he was observing a living micro-organism. The same was true of the extra-corpuscular flagellate bodies which may be seen to undergo very active movements, as a result of which the red blood corpuscles are violently displaced and the flagellate body itself dashes about in the field of view.

The first confirmation in this country of Laveran's discovery of amœboid parasites in the blood of malarial-fever patients was made by myself in the pathological laboratory of the Johns Hopkins University in March, 1886. In May, 1885, I had visited Rome as a delegate to the International Sanitary Conference, convened in that city under the auspices of the Italian Government, and while there I visited the Santo Spirito Hospital for the purpose of witnessing a demonstration, by Drs. Marchiafava and Celli, of that city, of the presence of the *plasmodium malariæ* in the blood of persons suffering from intermittent fever. Blood was drawn from the finger during the febrile attack and from individuals to whom quinine had not been administered. The demonstration was entirely satisfactory, and no doubt was left in my mind that I saw living parasitic micro-organisms in the interior of red blood corpuscles obtained from the circulation of malarial-fever patients. The motions were quite slow, and were manifested by a gradual change of outline rather than by visible movement. After a period of amœboid activity of greater or less duration, the body again assumed an oval or spherical form and remained quiescent for a time. While in this form it was easily recognized, as the spherical shape caused the light passing through it to be refracted, and gave the impression of a body having a dark contour and a central vacuole, but when it was flattened out and undergoing amœboid changes in form it was necessary to focus very carefully and to have a good illumination in order to see it. The objective used was a Zeiss' one-twelfth inch homogeneous oil immersion.

But, very properly, skepticism with reference to the casual

relation of these bodies to the disease with which they are associated was not removed by the demonstration that they are in fact blood parasites, that they are present in considerable numbers during the febrile paroxysms, and that they disappear during the interval between these paroxysms. These facts, however, give strong support to the inference that they are indeed the cause of the disease. This inference is further supported by the evident destruction of red blood corpuscles by the parasite, as shown by the presence of grains of black pigment in the amœba-like micro-organisms observed in these corpuscles and the accumulation of this insoluble blood pigment in the liver and spleen of those who have suffered repeated attacks of intermittent fever. The enormous loss of red blood corpuscles as a result of such attacks is shown by the anæmic condition of the patient and also by actual enumeration. According to Kelsch, a patient of vigorous constitution in the first four days of a quotidian intermittent fever, or a remittent of first invasion, may suffer a loss of 2,000,000 of red blood corpuscles per cubic millimeter of blood, and in certain cases a loss of 1,000,000 has been verified at the end of twenty-four hours. In cases of intermittent fever having a duration of twenty to thirty days the number of red blood cells may be reduced from the normal, which is about 5,000,000 per cubic millimeter, to 1,000,000, or even less. In view of this destruction of the red blood cells and the demonstrated fact that a certain number at least are destroyed during the febrile paroxysms by a blood parasite which invades the cells and grows at the expense of the continued hæmoglobin, it may be thought that the etiological rôle of the parasite should be conceded. But scientific conservatism demands more than this, and the final proof has been afforded by the experiments of Gerhardt and of Marchiafava and Celli — since confirmed by many others. This proof consists in the experimental inoculation of healthy individuals with blood containing the parasite and the development of a typical attack of periodic fever as a result of such inoculation. Marchiafava and Bignami, in their elaborate article upon "Malaria," published in the "Twentieth Century Practice of Medicine," say:

> The transmission of the disease occurs equally whether the blood is taken during the apyretic period or during a febrile paroxysm, whether it contains young parasites or those in process of development, or whether it

contains sporulation forms. Only the crescent forms, when injected alone, do not transmit the infection, as has been demonstrated by Bastianelli, Bignami, and Thayer, and as can be readily understood when we remember the biological significance of these forms.

In order that the disease be reproduced in the inoculated subject, it is not necessary to inject the malarial blood into a vein of the recipient, as has been done in most of the experiments; as subcutaneous injection is all-sufficient. Nor is it necessary to inject several cubic centimeters as was done especially in the earlier experiments; a fraction of a cubic centimeter will suffice and even less than one drop, as Bignami has shown.

After the inoculation of a healthy individual with blood containing the parasite a period varying from four to twenty-one days elapses before the occurrence of a febrile paroxysm. This is the so-called period of incubation, during which, no doubt, the parasite is undergoing multiplication in the blood of the inoculated individual. The duration of this period depends to some extent upon the quantity of blood used for the inoculation and its richness in parasites. It also depends upon the particular variety of the parasite present, for it has been ascertained that there are at least three distinct varieties of the malarial parasite — one which produces the quartan type of fever, in which there is a paroxysm every third day and in which, in experimental inoculations made, the period of incubation has varied from eleven to eighteen days; in the tertian type, or second day fever, the period of incubation noted has been from nine to twelve days; and in the æstivo-autumnal type the duration has usually not exceeded five days. The parasite associated with each of these types of fever may be recognized by an expert, and there is no longer any doubt that the difference in type is due to the fact that different varieties or " species " of the malarial parasite exist, each having a different period of development. Blood drawn during a febrile paroxysm shows the parasite in its different stages of intra-corpuscular development. The final result of this development is a segmenting body, having pigment granules at its center, which occupies the greater part of the interior of the red corpuscle. The number of segments into which this body divides differs in the different types of fever, and there are other points of difference by which the several varieties may be distinguished one from the other, but which it is not necessary to mention at the present time. The important point is that the result of the segmentation of the adult parasites contained in the

red corpuscles is the formation of a large number of spore-like bodies, which are set free by the disintegration of the remains of the blood corpuscles and which constitute a new brood of reproductive elements, which in their turn invade healthy blood corpuscles and effect their destruction. This cycle of development, without doubt, accounts for the periodicity of the characteristic febrile paroxysms; and, as stated, the different varieties complete their cycle of development in different periods of time, thus accounting for the recurrence of the paroxysms at intervals of forty-eight hours in one type of fever and of three days in another type. When a daily paroxysm occurs, this is believed to be due to the alternate development of two groups of parasites of the tertian variety, as it has not been possible to distinguish the parasite found in the blood of persons suffering from a quotidian form of intermittent fever from that of the tertian form. Very often, also, the daily paroxysm occurs on succeeding days at a different hour, while the paroxysm every alternate day is at the same hour, a fact which sustains the view that we have to deal, in such cases, with two broods of the tertian parasite which mature on alternate days. In other cases there may be two distinct paroxysms on the same day and none on the following day, indicating the presence of two broods of tertian parasites maturing at different hours every second day.

Manson, in his work on tropical diseases, recently published, accounts for the febrile paroxysm as follows:

> In all malarial attacks this periodicity tends to become, and in most attacks actually is, quotidian, tertian, or quartan in type. If we study the parasites associated with these various types we find that they, too, as has been fully described already, have a corresponding periodicity. We have also seen that the commencement of the fever in each case corresponds with the breaking up of the sporulating form of the parasite concerned. This last is an important point; for, doubtless, when this breaking up takes place, besides the pigment set free, other residual matters — not so striking optically, it is true, as the pigment, but none the less real — probably are liberated; a hæmoglobin solvent, for example, as I have suggested. Whether it be this hæmoglobin solvent, or whether it be some other substance, which is the pyrogenetic agent, I believe that some toxin, hitherto inclosed in the body of the parasite, or in the infected corpuscle, escapes into the blood at the moment of sporulation.
>
> The periodicity of the clinical phenomena is accounted for by the periodicity of the parasite. How are we to account for the periodicity of the parasite? It is true that it has a life of twenty-four hours, or of a multi-

ple of twenty-four hours; but why should the individual parasites of the countless swarm all conspire to mature at or about the same time? That they do so — not perhaps exactly at the same moment, but within a very short time of each other — is a fact, and it is one which can be easily demonstrated. If we wish to see the sporulating forms of the plasmodium in a pure intermittent, it is practically useless to look for them in the blood during the later stages of fever, or during the interval, or during any time but just before, during, or soon after rigor. If we wish to see the early and unpigmented forms, we must look for them during the later stage of rigor or the earlier part of the stage of pyrexia. And so with the other stages of the parasite; each has its appropriate relationship to the fever cycle.

There are numerous cases of malarial fever in which there is no distinct intermission and in which the course of the fever is either continued or remittent in character. Fevers of this type usually occur in the late summer or in the autumn (æstivo-autumnal) and are believed to be due to infection by two distinct varieties of the parasite; one, the tertian æstivo-autumnal, causes a fever characterized by a marked rise in the temperature every second day; the other a fever in which there is a daily elevation of temperature. There are certain peculiarities relating to the intra-corpuscular development of these parasites which enables us to differentiate them from the tertian and quartan parasites of intermittent fever, but a more striking difference to be observed in their life cycle of development in the blood of man is the presence of peculiar crescentic-shaped bodies, which play an important part in their further development in the body of an intermediate host — the mosquito. Associated with these "crescents" fusiform and ovoid bodies are often seen which are no doubt similar in their origin and function. The crescents are a little longer than the diameter of a red blood corpuscle and are about three times as long as broad. They contain in the central portion grains of pigment (melanin) derived from the hæmoglobin of the infected corpuscle, which has been changed into a crescentic body as a result of the development of the malarial parasite in its interior. When a fresh preparation of malarial blood containing these crescents is observed under the microscope, while a majority of them retain the crescentic form, others may be seen, after an interval of ten minutes or more, to change in form, first becoming oval and then round; then, in the interior of these round bodies an active movement of the pigment

granules occurs; this is followed by the thrusting forth from the periphery of several filaments — usually four — which have flagella-like movements. These, as a rule, become detached and continue to move rapidly among the blood corpuscles. With reference to the function of these motile filaments, Marchiafava says:

> In these later days there is increasing belief in the theory, which we uphold, that the crescents and the flagellata are sexual forms of the malarial parasite, and that a reproductive act (in which the flagellum represents the male element and an adult crescent the female cell) gives rise to the new being which begins its existence in the tissues of the mosquito.

The crescentic bodies may be found in the blood of man long after all febrile symptoms have disappeared, and it is generally recognized that they are not directly concerned in the production of the phenomena which constitute a malarial attack and that the administration of quinine has no influence in causing them to disappear from the blood. On the other hand, the febrile phenomena are directly associated with the appearance of the amœboid form of the parasite in the interior of the red blood corpuscles, and the administration of suitable doses of quinine has a marked effect in causing these amœbo-like micro-organisms to disappear from the blood.

These crescentic bodies are not found in the benign tertian and quartan intermittent fevers, but are characteristic of the malignant forms of malarial infection, including the so-called æstivo-autumnal fever. In these forms of fever they are not seen at the outset of the attack, and they have no direct influence upon the course of the fever. A week usually elapses between the first appearance of the amœboid form of the parasite and that of these crescentic bodies. They are often found in the blood some time after all symptoms of fever have disappeared, and are associated with the malarial cachexia which follows an attack of æstivo-autumnal fever. When blood containing these crescents is ingested by a mosquito of the genus *Anopheles,* the following very remarkable transformations occur: Some of the crescents are transformed into hyaline flagellate bodies having active movements; others are changed into granular spheres. The flagella break away from the hyaline bodies and, approaching the granular spheres, appear to seek energetically to enter

these bodies. A minute papilla is given off from the surface of the sphere, seeming to be projected to meet the attacking flagellum. At this point, one of the flagella succeeds in entering the sphere, causing an active movement of its contents for a brief time, after which the flagellum disappears from view and the contents become quiescent. This is no doubt an act of impregnation. After a time the impregnated granular sphere alters its shape, becoming oval, and later vermicular in form. The pigment granules are now seen at the posterior part of this body, which, after the changes mentioned, exhibits active movements. It is believed that this motile vermicular body penetrates the wall of the mosquito's stomach. Here it grows rapidly and, after a few days, may be seen projecting from the surface as a spherical mass. In the meantime the contents are transformed into spindle-shaped bodies (sporozoites) which are subsequently set free by the rupture of the capsule of the mother cell. According to Manson, these spindle-shaped bodies pass from the body cavity of the mosquito, probably by way of the blood, to the 3-lobed veneno-salivary glands lying on each side of the fore part of the thorax of the insect. "These glands communicate with the base of the mosquito's proboscis by means of a long duct, along the radicles of which the clear, plump cells of the gland are arranged. The sporozoites can be readily recognized in many, though not in all, of the cells, especially in those of the middle lobe, and also free in the ducts. So numerous are they in some of the cells that the appearance they present is suggestive of a bacillus-laden lepra-cell."

The hypothesis that malarial infection results from the bites of mosquitoes was advanced and ably supported by Dr. A. F. A. King, of Washington, D. C., in a paper read before the Philosophical Society on February 10, 1883, and published in the Popular Science Monthly in September of the same year. In 1894 Manson supported the same hypothesis in a paper published in the British Medical Journal (December 8), and the following year (1895) Ross made the important discovery that when blood containing the crescentic bodies was ingested by the mosquito these crescents rapidly underwent changes similar to those heretofore described, resulting in the formation of motile filaments, which become detached from the parent body and continue to exhibit active movements. In 1897 Ross ascertained

further that when blood containing crescents was fed to a particular species of mosquito, living pigmented parasites could be found in the stomach walls of the insect. Continuing his researches with a parasite of the same class which is found in birds, and in which the mosquito also serves as an intermediate host, Ross found that this parasite enters the stomach wall of the insect, and, as a result of its development in that locality, forms reproductive bodies (sporozoites), which subsequently find their way to the veneno-salivary glands of the insect which is now capable of infecting other birds of the same species as that from which the blood was obtained in the first instance. Ross further showed that the mosquito which served as an intermediate host for this parasite could not transmit the malarial parasite of man or another similar parasite of birds (halteridium). These discoveries of Ross have been confirmed by Grassi, Koch, and others, and it has been shown that the mosquitoes which serve as intermediate hosts for the malarial parasites of man belong to the genus *Anopheles,* and especially to the species known as *Anopheles claviger.*

The question whether mosquitoes infected with the malarial parasite invariably become infected as a result of the ingestion of human blood containing this parasite has not been settled in a definite manner, but certain facts indicate that this is not the case. Thus there are localities noted for being extremely dangerous on account of the malarial fevers contracted by those who visit them, which on this very account are rarely visited by man. Yet there must be a great abundance of infected mosquitoes in these localities, and especially in low, swampy regions in the Tropics. If man and the mosquitoes are alone concerned in the propagation of this parasite, how shall we account for the abundance of infected mosquitoes in uninhabited marshes? It appears probable that some other vertebrate animal serves in place of man to maintain the life cycle of the parasite, or that it may be propagated through successive generations of mosquitoes.

It is well known that persons engaged in digging canals, railroad cuts, etc., in malarious regions are especially liable to be attacked with one or the other of the forms of malarial fever. This may be due to the fact that the digging operations result in the formation of little pools suitable for the development of the eggs of *Anopheles;* but another explanation has been offered.

Ross and others have found in infected mosquitoes certain bodies, described by Ross as "black spores," which resist decomposition and which may be resting spores capable of retaining their vitality for a long time. The suggestion is that these "black spores" or other encysted reproductive bodies may have been deposited in the soil by mosquitoes long since defunct, "and that in moving the soil these dormant parasites are set at liberty, and so in air, in water, or otherwise gain access to the workmen engaged" (Manson). This hypothesis is not supported by recent observations, which indicate that infection in man occurs only as a result of inoculation through the bite of an infected mosquito. The question is whether malarial fevers can be contracted in marshy localities independently of the mosquito, which has been demonstrated to be an intermediate host of the malarial parasite? Is this parasite present in the air or water in such localities, as well as in the bodies of infected mosquitoes? Its presence has never been demonstrated by the microscope; but this fact has little value in view of the great variety of micro-organisms present in marsh water or suspended in the air everywhere near the surface of the ground, and the difficulty of recognizing the elementary reproductive bodies by which the various species are maintained through successive generations. It would appear that a crucial experiment for the determination of this question would be to expose healthy individuals in a malarious region and to exclude the mosquito by some appropriate means. This experiment has been made during the past summer, and the result up to the present time has been reported by Manson in the London *Lancet* of September 29. Five healthy individuals have lived in a hut on the Roman Campagna since early in the month of July. They have been protected against mosquito bites by mosquito-netting screens in the doors and windows and by mosquito bars over the beds. They go about freely during the daytime, but remain in their protected hut from sunset to sunrise. At the time Manson made his report all these individuals remained in perfect health. It has long been known that laborers could come from the villages in the mountainous regions near the Roman Campagna and work during the day, returning to their homes at night, without great danger of contracting the fever, while those who remained on the Campagna at night ran great risk of falling sick with fever,

as a result of "exposure to the night air." What has already been said makes it appear extremely probable that the "night air," per se, is no more dangerous than the day air, but that the real danger consists in the presence of infected mosquitoes of a species which seeks its food at night. As pointed out by King, in his paper already referred to, it has repeatedly been claimed by travelers in malarious regions that sleeping under a mosquito bar is an effectual method of prophylaxis against intermittent fevers.

That malarial fevers may be transmitted by mosquitoes of the genus *Anopheles* was first demonstrated by the Italian physician Bignami, whose experiments were made in the Santo Spirito Hospital in Rome. The subjects of the experiment, with their full consent, were placed in a suitable room and exposed to the bites of mosquitoes brought from Maccarese, "a marshy place with an evil but deserved reputation for the intensity of its fevers." It has been objected to these experiments that they were made in Rome, at a season of the year when malarial fevers prevail to a greater or less extent in that city, but Marchiafava and Bignami say:

> It is well known to all physicians here that, although there are some centers of malaria in certain portions of the suburbs, the city proper is entirely free from malaria, as long experience has demonstrated, and at no season of the year does one acquire the disease in Rome.

In view of the objection made, a crucial experiment has recently been made in the city of London. The result is reported by Manson, as follows:

> Mosquitoes infected with the parasite of benign tertian malarial fever were sent from Rome to England, and were allowed to feed upon the blood of a perfectly healthy individual (Dr. Manson's son, who had never had malarial disease). Forty mosquitoes in all were allowed to bite him between August 29 and September 12. On September 14 he had a rise of temperature, with headache and slight chilliness, but no organisms were found in his blood. A febrile paroxysm occurred daily thereafter, but the parasites did not appear in the blood until September 17, when large numbers of typical tertian parasites were found. They soon disappeared under the influence of quinine.
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> Quoted from an editorial in the New York Medical Journal of October 20, 1900.

We have still to consider the question of the transmission of

malarial fevers by the ingestion of water from malarious localities. Numerous medical authors have recorded facts which they deemed convincing as showing that malarial fevers may be contracted in this way. I have long been of the opinion that while the observed facts may, for the most part, be authentic, the inference is based upon a mistake in diagnosis; that, in truth, the fevers which can justly be ascribed to the ingestion of a contaminated water supply are not true malarial fevers — i. e., they are not due to the presence of the malarial parasite in the blood. This view was sustained by me in my work on "Malaria and Malarial Diseases," published in 1883. The fevers supposed to have been contracted in this way are, as a rule, continued or remittent in character, and they are known under a variety of names. Thus we have "Roman fever," "Naples fever," "remittent fever," "mountain fever," "typho-malarial fever," etc. The leading physicians and pathologists, in regions where these fevers prevail, are now convinced that they are not malarial fevers, but are simply more or less typical varieties of typhoid fever — a disease due to a specific bacillus and which is commonly contracted as a result of the ingestion of contaminated water or food. The error in diagnosis, upon which the inference has been based that malarial fevers may be contracted through drinking water, has been widespread, in this country, in Europe and the British possessions in India. It vitiated our medical statistics of the Civil War and of the recent war with Spain. In my work already referred to I say:

> Probably one of the most common mistakes in diagnosis, made in all parts of the world where malarial and enteric fevers are endemic, is that of calling an attack of fever belonging to the last-mentioned category malarial remittent. This arises from the difficulties attending a differential diagnosis at the outset, and from the fact that having once made a diagnosis of malarial fever the physician, even if convinced later that a mistake has been made, does not always feel willing to confess it. The case, therefore, appears in the mortality returns if it prove fatal, or in the statistical reports of disease if made by an army or navy surgeon, as at first diagnosed.

I have already mentioned the fact that Marchiafava denies that malarial fevers prevail in the city of Rome, yet everyone knows how frequently travelers contract the so-called "Roman fever" as a result of a temporary residence in that city. In our

own cities numerous cases of so-called "remittent" or "typho-malarial" fevers are reported in localities where typical malarial fevers (intermittents) are unknown, and at seasons of the year when these fevers do not prevail even in the marshy regions where they are of annual occurrence, during the mosquito season. Malarial fevers may, of course, occur in cities as a result of exposure elsewhere to the bites of infected mosquitoes of the genus *Anopheles,* either as primary attacks or as a relapse, or in urban localities in the vicinity of marshy places or pools of water suitable as breeding places for *Anopheles.* But when a previously healthy individual, living in a well-paved city, in a locality remote from all swampy places is taken sick with a "remittent fever," and especially when the attack occurs during the winter months, it is pretty safe to say that he is not suffering from malarial infection, and the chances are greatly in favor of the view that he has typhoid fever. It must be remembered that remittent or intermittent course is not peculiar to malarial fevers. Typhoid commonly presents a more or less remittent character, especially at the outset of an attack; the hectic fever of tuberculosis is intermittent in character. The formation of an abscess, an attack of tonsilitis, etc., are usually attended by chills and fever, which may recur at more or less regular intervals. Indeed, in certain cases of pyæmia the febrile phenomena are so similar to those of a malarial attack that a mistake in diagnosis is no unusual occurrence. Finally, I may say that it is the fashion with many persons and with some physicians to ascribe a variety of symptoms, due to various causes, to "malaria" and to prescribe quinine as a general panacea. Thus a gentleman who has been at the club until 1 or 2 o'clock at night and has smoked half a dozen cigars — not to mention beer and cheese sandwiches as possible factors — reports to his doctor the next morning with a dull headache, a furred tongue, and a loss of appetite which he is unable to account for except upon the supposition that he has "malaria." Again the symptoms arising from indigestion, from crowd poisoning, from sewer-gas poisoning, from ptomaine poisoning (auto-infection), etc., are often ascribed to "malaria," and quinine is prescribed, frequently with more or less benefit, for the usefulness of this drug is not limited to its specific action in the destruction of the malarial parasite.

As stated at the outset, it is evident, in the present state of our knowledge, that the term "malaria" is a misnomer, either as applied to the cause of the periodic fevers or as used to designate this class of fevers. It would be more logical to use the name plasmodium fever and to speak of a plasmodium intermittent or remittent, rather than of a malarial intermittent. But it will, no doubt, be difficult to displace a term which has been so long in use, which up to the present time has had the sanction of the medical profession, and which expresses the popular idea as to the origin of that class of fevers which we now know to be due to a blood parasite, introduced through the agency of mosquitoes of the genus *Anopheles*.

FIGHTING PESTS WITH INSECT ALLIES.*

By LELAND O. HOWARD.

SOME twenty-five years ago there appeared suddenly upon certain acacia trees at Menlo Park, California, a very destructive scale bug. It rapidly increased and spread from tree to tree, attacking apples, figs, pomegranates, quinces, and roses, and many other trees and plants, but seeming to prefer to all other food the beautiful orange and lemon trees which grow so luxuriantly on the Pacific Coast, and from which a large share of the income of so many fruit-growers is gained. This insect, which came to be known as the *white scale* or *fluted scale* or the *Icerya* (from its scientific name), was an insignificant creature in itself, resembling a small bit of fluted white wax a little more than a quarter of an inch long. But when the scales had once taken possession of a tree, they swarmed over it until the bark was hidden, they sucked its sap through their minute beaks until the plant became so feeble that the leaves and young fruit dropped off, a hideous black smut-fungus crept over the young twigs, and the weakened tree gradually died.

In this way orchard after orchard of oranges, worth a thousand dollars or more an acre, was utterly destroyed, the best fruit-growing sections of the State were invaded, and ruin stared many a fruit-grower in the face. This spread of the pest was gradual, extending through a series of years, and not until 1886 did it become so serious a matter as to attract national attention.

In this year an investigation was begun by the late Professor C. V. Riley, the government entomologist then connected with

* It has been very customary to poke fun at some of the more detailed labors of our Department of Agriculture, and to question scornfully what use the mass of data collected could be to the practical farmer. The few instances here given of the Department's work (showing how the Government scientists have repeatedly saved the fruit-growers from utter ruin and have made it possible to build up great agricultural industries) form an apt answer to such short-sighted criticisms.

the Department of Agriculture at Washington. He sent two agents to California, both of whom immediately began to study the problem of remedies. In 1887 he visited California himself, and during that year published an elaborate report giving the results of the work up to that point. The complete life-history of the insect had been worked out, and a number of washes had been discovered which could be applied to the trees in the form of a spray, and which would kill a large proportion of the pests at a comparatively small expense. But it was soon found that the average fruit-grower would not take the trouble to spray his trees, largely from the fact that he had experimented for some years with inferior washes and quack nostrums, and from lack of success had become disgusted with the whole idea of using liquid compounds. Something easier, something more radical was necessary in his disheartened condition.

Meantime, after much sifting of evidence and much correspondence with naturalists in many parts of the world, Professor Riley had decided that the white scale was a native of Australia, and had been first brought over to California accidentally upon Australian plants. In the same way it was found to have reached South Africa and New Zealand, in both of which colonies it had greatly increased, and had become just such a pest as it is in California. In Australia, however, its native home, it did not seem to be abundant, and was not known as a pest — a somewhat surprising state of affairs, which put the entomologist on the track of the results which proved of such great value to California. He reasoned that, in its native home, with the same food plants upon which it flourished abroad in such great abundance, it would undoubtedly do the same damage that it does in South Africa, New Zealand, and California, if there were not in Australia some natural enemy, probably some insect parasite or predatory beetle, which killed it off. It became therefore important to send a trained man to Australia to investigate this promising line.

After many difficulties in arranging preliminaries relating to the payment of expenses (in which finally the Department of State kindly assisted), one of Professor Riley's assistants, a young German named Albert Koebele, who had been with him for a number of years, finally sailed for Australia in August, 1888. Koebele was a skilled collector and an admirable man for

the purpose. He at once found that Professor Riley's supposition was correct: there existed in Australia small flies which laid their eggs in the white scales, and these eggs hatched into grubs which devoured the pests. He also found a remarkable little ladybird, a small reddish-brown convex beetle, which breeds with marvelous rapidity and which, with voracious appetite and at the same time with discriminating taste, devours scale after scale, but eats fluted scales only — does not attack other insects. This beneficial creature, now known as the Australian ladybird, or the Vedalia, Mr. Koebele at once began to collect in large numbers, together with several other insects found doing the same work. He packed many hundreds of living specimens of the ladybird, with plenty of food, in tin boxes, and had them placed on ice in the ice-box of the steamer at Sidney; they were carried carefully to California, where they were liberated upon orange trees at Los Angeles.

Vedalia or Australian Ladybird.

These sendings were repeated for several months, and Mr. Koebele, on his return in April, 1889, brought with him many more living specimens which he had collected on his way home in New Zealand, where the same Vedalia had been accidentally introduced a year or so before.

The result more than justified the most sanguine expectations. The ladybirds reached Los Angeles alive, and, with appetites sharpened by their long ocean voyage, immediately fell upon the devoted scales and devoured them one after another almost without rest. Their hunger temporarily satisfied, they began to lay eggs. These eggs hatched in a few days into active grub-like creatures — the larvæ of the beetles — and these grubs proved as voracious as their parents. They devoured the scales right and left, and in less than a month transformed once more to beetles.

And so the work of extermination went on. Each female beetle laid on an average 300 eggs, and each of these eggs hatched into a hungry larva. Supposing that one-half of these larvæ produced female beetles, a simple calculation will show that in six months a single ladybird became the ancestor of

75,000,000,000 of other ladybirds, each capable of destroying very many scale insects.

Is it any wonder, then, that the fluted scales soon began to disappear? Is it any wonder that orchard after orchard was entirely freed from the pest, until now over a large section of the State hardly an Icerya is to be found? And could a more striking illustration of the value of the study of insects possibly be instanced? In less than a year from the time when the first of these hungry Australians was liberated from his box in Los Angeles the orange trees were once more in bloom and were resuming their old-time verdure—the Icerya had become practically a thing of the past.

Larvæ of Vedalia Eating White Scale.

This wonderful success encouraged other efforts in the same direction. The State of California some years later sent the same entomologist, Koebele, to Australia to search for some insect enemy of the black scale, an insect which threatened the destruction of the extensive olive orchards of California. He found and successfully introduced another ladybird beetle, known as *Rhizobius ventralis,* a little dark-colored creature which has thrived in the California climate, especially near the seacoast, and in the damp air of those regions has successfully held the black scale in check. It was found, however, that back from the seacoast this insect did not seem to thrive with the same vigor, and the black scale held its own — in some places more than held its own. Then a spirited controversy sprung up among the olive-growers, those near the seacoast contending that the Rhizobius was a perfect remedy for the scale, while those inland insisted that it was worthless. A few years later it was discovered that this olive enemy in South Europe is killed by a little caterpillar which burrows through scale after scale, eating out their contents, and an effort was made to introduce the caterpillar into California, but these efforts failed. Within the past two years

it has been found that a small parasitic fly exists in South Africa which lays its eggs in this same black scale, and its grub-like larvæ eat out the bodies of the scales and destroy them. The climate of the region in which this parasite exists is dry through a large part of the year, and therefore this little parasitic fly, known as Scutellista, was thought to be the needed insect for the dry California regions. With the help of Mr. C. P. Lounsbury, the government entomologist of Cape Colony, living specimens of this fly were brought to this country, and were colonized in the Santa Clara Valley near San José, California, where they have perpetuated themselves and destroyed many of the black scales, and promise to be most successful in their warfare against the injurious insect.

This same Scutellista parasite had, curiously enough, been previously introduced in an accidental manner into Italy, probably from India, and probably in scale-insects living on ornamental plants brought from India. But in Italy, it lives commonly in another scale insect, and with the assistance of the learned Italian, Professor Antonio Berlese, the writer made an unsuccessful attempt to introduce and establish it a year earlier in some of our Southern States, where it was hoped it would destroy certain injurious insects known as "wax scales."

In the meantime, the United States, not content with keeping all the good things to herself, has spread the first ladybird imported — the Vedalia — to other countries. Four years ago the white scale was present in enormous numbers in orange groves on the left bank of the river Tagus, in Portugal, and threatened to wipe out the orange-growing industry in that country. The California people, in pursuance of a far-sighted policy, had with great difficulty, owing to lack of food, kept alive some colonies of the beneficial beetle, and specimens were sent to Portugal which reached there alive and flourishing. They were tended for a short time, and then liberated in the orange groves, with precisely the same result as in California. In a few months the scale insects were almost entirely destroyed, and the Portuguese orange-growers saved from enormous loss.

This good result in Portugal was not accomplished without opposition. It was tried experimentally at the advice of the writer, and in the face of great incredulity on the part of certain Portuguese newspapers and of some officials. By many

prominent persons the account published of the work of the insect in the United States was considered as untrustworthy, and simply another instance of American *réclame* (brag). But the opposition was overruled, and the triumphant result silenced all opposition. It is safe to say that the general opinion among Portuguese orange-growers to-day is very favorable to American enterprise and practical scientific acumen.

The Vedalia was earlier sent to the people in Alexandria and Cairo, Egypt, where a similar scale was damaging the fig trees and other valuable plants, and the result was again the same, the injurious insects were destroyed. This was achieved only after extensive correspondence and several failures. The active agent in Alexandria was Rear Admiral Blomfield, of the British Royal Navy, a man apparently of wide information, good judgment, and great energy.

The same thing occurred when the California people sent this savior of horticulture to South Africa, where the white scale had also made its appearance.

It is not only beneficial insects, however, which are being imported, but diseases of injurious insects. In South Africa the colonists suffer severely from swarms of migratory grasshoppers which fly from the north and destroy their crops. They have discovered out there a fungus disease which under favorable conditions kills off the grasshoppers in enormous numbers. At the Bacteriological Institute in Grahamstown, Natal, they have cultivated this fungus in culture tubes, and have carried it successfully throughout the whole year; and they have used it practically by distributing these culture tubes wherever swarms of grasshoppers settle and lay their eggs. The disease, once started in an army of young grasshoppers, soon reduces them to harmless numbers. The United States Government last year secured culture tubes of this disease, and experiments carried on in Colorado and in Mississippi show that the vitality of the fungus had not been destroyed by its long ocean voyage, and many grasshoppers were killed by its spread. During the past winter other cultures were brought over from Cape Colony, and the fungus is being propagated in the Department of Agriculture for distribution during the coming summer in parts of the country where grasshoppers may prove to be destructively abundant.

Although we practically no longer have those tremendous

swarms of migratory grasshoppers which used to come down like devastating armies in certain of our Western States and in a night devour everything green (even the Irish servant-girls, as those who joke over serious matters used to say), still, almost every year, and especially in the West and South, there is somewhere a multiplication of grasshoppers to a very injurious degree, and it is hoped that the introduced fungus can be used in such cases.

Persons officially engaged in searching for remedies for injurious insects all over the world have banded themselves together in a society known as the Association of Economic Entomologists. They are constantly interchanging ideas regarding the destruction of insects, and at present active movements are on foot in this direction of interchanging beneficial insects. Entomologists in Europe will try the coming summer to send to the United States living specimens of a tree-inhabiting beetle which eats the caterpillar of the gipsy moth, and which will undoubtedly also eat the caterpillar so common upon the shade-trees of our principal Eastern cities, which is known as the Tussock moth caterpillar. An entomologist from the United States, Mr. C. L. Marlatt, has started for Japan, China, and Java, for the purpose of trying to find the original home of the famous San José scale — an insect which has been doing enormous damage in the apple, pear, peach, and plum orchards of the United States — and if he finds the original home of this scale, it is hoped that some natural enemy or parasite will be discovered which can be introduced into the United States to the advantage of our fruit-growers. Professor Berlese, of Italy, and Dr. Reh, of Germany, will attempt the introduction into Europe of some of the parasites of injurious insects which occur in the United States, and particularly those of the woolly root-louse of the apple, known in Europe as the "American blight" — one of the few injurious insects which probably went to Europe from this country, and which in the United States is not so injurious as it is in Europe.

It is a curious fact by the way, that while we have had most of our very injurious insects from Europe, American insects, when accidentally introduced into Europe, do not seem to thrive. The insect just mentioned, and the famous grapevine Phylloxera, a creature which caused France a greater economic

loss than the enormous indemnity which she had to pay Germany after the Franco-Prussian War, are practically the only American insects with which we have been able to repay Europe for the insects which she has sent us. Climatic differences no doubt account for this strange fact, and our longer and warmer summers are the principal factor.

It is not alone the parasitic and predaceous insects which are beneficial. A new industry has been brought into the United

Grasshopper Dying From Fungus Disease.

States during the past two years by the introduction and acclimatization of the little insect which fertilizes the Smyrna fig in Mediterranean countries. The dried-fig industry in this country has never amounted to anything. The Smyrna fig has controlled the dried-fig markets of the world, but in California the Smyrna fig has never held its fruit, the young figs dropping from the trees without ripening. It was found that in Mediterranean

regions a little insect known as the Blastophaga fertilizes the flowers of the Smyrna fig with pollen from the wild fig which it inhabits. The United States Department of Agriculture in the spring of 1899 imported successfully some of these insects through one of its traveling agents, Mr. W. T. Swingle, and the insect was successfully established at Fresno in the San Joaquin Valley. A far-sighted fruit-grower, Mr. George C. Roeding, of Fresno, had planted some years previously an orchard of 5,000 Smyrna fig trees and wild fig trees, and his place was the one chosen for the successful experiment. The little insect multiplied with astonishing rapidity, was carried successfully

The Imported Fig-Fertilizing Insect.

through the winter of 1899–1900, and in the summer of 1900 was present in such great numbers that it fertilized thousands of figs, and fifteen tons of them ripened. When these figs were dried and packed it was discovered that they were superior to the best imported figs. They contained more sugar and were of a finer flavor than those brought from Smyrna and Algeria. The Blastophaga has come to stay, and the prospects for a new and important industry are assured.

With all of these experiments the criticism is constantly made that unwittingly new and serious enemies to agriculture may be introduced. The unfortunate introduction of the English sparrow into this country is mentioned, and the equally unfortunate introduction of the East Indian mongoose into the West Indies as well. The fear is expressed that the beneficial parasitic insects, after they have destroyed the injurious insects, will either

themselves attack valuable crops or do something else of an equally harmful nature. But there is no reason for such alarm. The English sparrow feeds on all sorts of things, and the East Indian mongoose, while it was introduced into Jamaica to kill snakes, was found, too late, to be also a very general feeder. As a matter of fact, after the snakes were destroyed, and even before, it attacked young pigs, kids, lambs, calves, puppies, and kittens, and also destroyed bananas, pine-apples, corn, sweet potatoes, cocoanuts, peas, sugar corn, meat, and salt provisions and fish. But with the parasitic and predatory insects the food habits are definite and fixed. They can live on nothing but their natural food, and in its absence they die. The Australian lady-bird originally imported, for example, will feed upon nothing but scale insects of a particular genus, and, as a matter of fact, as soon as the fluted scales became scarce the California officials had the greatest difficulty in keeping the little beetles alive, and were actually obliged to cultivate for food the very insects which they were formerly so anxious to wipe out of existence! With the Scutellista parasite the same fact holds. The fly itself does not feed, and its young feed only upon certain scale insects, and so with all the rest.

All of these experiments are being carried on by men learned in the ways of insects, and only beneficial results, or at the very least negative ones, can follow. And even where only one such experiment out a hundred is successful, what a saving it will mean!

We do not expect the time to come when the farmer, finding Hessian fly in his wheat, will have only to telegraph the nearest experiment station, "Send at once two dozen first-class parasites"; but in many cases, and with a number of different kinds of injurious insects, especially those introduced from foreign countries, it is probable that we can gain much relief by the introduction of their natural enemies from their original home.

GREATEST DISCOVERY OF THE AGE.

By ROBERT ROUTLEDGE.

THE indulgent reader who may have followed the course of the foregoing pages, will perhaps peruse the title of this article with some little bewilderment. His attention has been drawn to one after another of a series of remarkable and important discoveries, and he will naturally wonder what can be the discovery which is greater than any of these. Now, a discovery is great in proportion to the extent and importance of the results that flow from it. These results may be immediate and practical, as in the case of vaccination; or they may be scientific and intellectual, as in Newton's discovery of the identity of the force which draws a stone to the ground with that which holds the planets in their orbits. Such discoveries as most enlarge our knowledge of the world in which we live, by embracing in simple laws a vast field of phenomena, are precisely those which are most prolific in useful applications. If we admit, as we must, the truth of Bacon's aphorism, which declares that "Man, as the minister and interpreter of nature, is limited in act and understanding by his observation of the order of nature; neither his understanding nor his power extends farther," then it would be easy to show that the discovery of which we have to treat, more than any other, must be of immense practical service to mankind in every one of the ways in which a knowledge of the order of nature can be of use, viz.:— "First, In showing us how to avoid attempting impossibilities. Second, In securing us from important mistakes in attempting what is, in itself, possible, by means either inadequate or actually opposed to the end in view. Third, In enabling us to accomplish our ends in the easiest, shortest, most economical, and most effectual manner. Fourth, In inducing us to attempt, and en-

abling us to accomplish, objects which, but for such knowledge, we should never have thought of undertaking."

A great principle, like that which we are about to explain to the reader, is too vast in its bearings for its discovery and elaboration to have been the work of an individual. This truth, and indeed the whole of our knowledge, is but the result of the development and growth of pre-existing knowledge. In fact, every discovery, however brilliant — every invention, however ingenious, is but the expansion or improvement of an antecedent discovery or invention. In strictness, therefore, it is impossible to say where the first germ of even our newest notions may be found. Our latest philosophy can be shown to be the result of progressive modifications of ideas of remote ages. Hence every great truth, every grand invention, has in reality been the offspring of many minds; but we record as *the* discoverers and inventors those men who have made the longest strides in the path of progress, and whose genius and labors have overcome obstacles defying ordinary efforts.

The extent of the field which is covered by the principle we have in view is so vast — embracing, as it does, the whole phenomena of the universe — that it will not be possible to do more within our limits than give the reader a general notion of the principle itself. It may be useful to instance a truth which has a similar generality and significance, and which has also acquired the force of an axiom, because it is verified every hour. It is that greatest generalization of chemistry, affirming that in all its transformations *matter is indestructible,* and can no more be destroyed than it can be called into being at will. This truth is so well established, that some philosophers have asserted than an opposite state of things is *inconceivable.* But it was not always known; and there are at the present day untutored minds which not only believe that a substance destroyed by fire is utterly annihilated, but what they find *inconceivable* is the continued existence of the substance in an invisible form. The candle burns away, its matter vanishes from our view; but if we collect the invisible products of the combustion, we find in them the whole substance of the candle in union with the atmospheric oxygen. We may, in imagination, follow the indestructible atoms of carbon in their migrations, from the atmosphere to the plant, which is eaten by the animal and goes to form its fat,

and from the tallow, by combustion, back into the atmosphere again. The notion of the real identity of matter under changing forms has been expressed by our great dramatist in a well-known passage, which is remarkable for its philosophic insight, when we consider the age in which it was written:

HAMLET. To what base uses we may return, Horatio! Why may not imagination trace the noble dust of Alexander, till he find it stopping a bung-hole?

HORATIO. 'Twere to consider too curiously to consider so.

HAMLET. No, faith, not a jot; but to follow him thither with modesty enough, and likelihood to lead it. As thus: Alexander died, Alexander was buried, Alexander returneth to dust; the dust is earth; of earth we make loam; and why of that loam, whereto he was converted, might they not stop a beer-barrel?

> Imperial Cæsar, dead, and turned to clay,
> Might stop a hole to keep the wind away;
> O, that the earth, which kept the world in awe,
> Should patch a wall to expel the winter's flaw!

Now the greatest discovery of our age is that force, like matter, is indestructible, and that it can no more be created than can matter. The reader may perhaps think the statement that we cannot create force is in contradiction to experience. He will be disposed to ask, What is the steam engine for but to create force? Do we not gain force by the pulley, the lever, the hydraulic press? And are not tremendous forces produced when we explode gunpowder or nitro-glycerine? When the principle with which we are here concerned has been developed and stated in accurate terms, it is hoped the reader will see the real nature of these contrivances. We are, however, aware that it is quite impossible within the limits of a short article to do much more than indicate a region of discovery abounding with results which may be yet unfamiliar to some. We may continue our task of merely illustrating the general nature of this, in reality the most important, subject which we have had occasion to bring under the reader's notice.

Perhaps the first step should be to point out the fact of the various forces of nature — mechanical action, heat, light, electricity, magnetism, chemical action — being so related that any one can be made to produce all the rest directly or indirectly. Some examples of the conversion of one form of force into an-

other occur in the foregoing pages. We have, indeed, sufficient examples to arrange a series of these conversions of forces in a circle. Thus, chemical action (oxidation in the animal system) supplies muscular power, this sets in motion a Gramme machine, the motion is converted into electricity, the electricity produces the electric light, and light causes chemical action, and with this the cycle is complete. In the steam engine heat is converted into mechanical force, and many cases will present themselves to the reader's mind in which mechanical actions give rise to heat. The doctrine of a mutual dependence and convertibility among all the forms of force was first definitively taught in England by Justice Grove, in 1842; and almost simultaneously Dr. Meyer promulgated similar views in Germany.

But this teaching included much more than a mere connection between the various forces, for it extended to quantitative relations. It declared that a given amount of one force always produced a definite amount of another; that a certain quantity of heat, for example, would give rise to a certain amount of mechanical action, and that this amount of mechanical action was the *equivalent of the heat* which produced it, and would in its turn reproduce all that heat. These last doctrines, however, rested on a speculative basis, until Mr. James Prescott Joule, of Manchester, carried out a most patient, laborious, and elaborate experimental investigation of the subject. His labors placed the truth of the numerical equivalence of forces on a foundation which cannot be shaken; and he accomplished for the principle of the indestructibility of force what Lavoisier did for that of the indestructibility of matter — he established it on the incontrovertible basis of accurate and conclusive experiment. His determination of the value of the *mechanical equivalent of heat* especially is a model of experimental research; and subsequent investigators have, by diversified methods, confirmed the accuracy of his results. A great part of his work consisted in finding what quantity of heat would be produced by a given quantity of *work*.

Before we proceed to give an indication of one of Dr. Joule's methods of making this determination, we may point out that if a weight be raised a certain height, the work which is done in raising it will be given out by the weight in its descent. If you carry a one pound weight to the top of a building 100 feet

high, you perform 100 units of work. When the weight is at the top, the work is not lost; for let the weight be attached to a cord passing over a pulley, and it will, as it descends, draw up to the top another one-pound weight.* If you drop the weight so that it falls freely, it descends with a continually increasing velocity, strikes the pavement, and comes to rest. Still your work is not lost. The collision of the weight and the pavement develops *heat*. The increase of temperature might not be sensible to the touch, but could be recognized by delicate instruments. Your work, then, has now changed into the form of heat — the weight and the pavement are hotter than before. This heat is carried off by contiguous substances. But still your work is not lost, for it has made the earth warmer. The heat, however, soon flows away by radiation from the earth, and is diffused into space. The final result of your work is, then, that a certain *measurable* quantity of heat has been sent off into space. Is your work now finally lost? Not so: in reality, it is

* The statement here should have been more explicit, as it has reference to a state of things not to be realized in practice. Like the well-known "first law of motion," it can neither be demonstrated *à priori*, nor proved by any direct and simple experiment. The first law of motion asserts that a body in motion, not acted on by any external force, will continue to move in a straight line, and with a uniform velocity. Now we cannot place a body in such a position that it will not be acted upon by some external forces; but the more we lessen the effect of external forces, the more nearly is the motion straight and uniform. Similarly in the case supposed, the intention is to show that the weight carried up is in a position to do just as much work as was done upon it. We must suppose several impracticable but conceivable conditions in order to eliminate considerations which do not concern the theoretical question; we must suppose the cord to be weightless and absolutely devoid of rigidity; the pulley to have no mass or inertia, that is to require no force to set it in motion, and to move without any friction; the air to offer no resistance; and the force of gravity to be uniform throughout the space. Some approximation to these conditions is practicable, as, for example, the pulley might be the lightest possible, and turn on friction wheels, the cord might be the finest silk thread, and so on. But it is not the influence of these external forces we are considering, but only the energy due to the position of the raised weight. Assuming, therefore, the disturbing conditions absolutely eliminated, it is not difficult to see that no downward force or pressure, however small, could be applied for ever so short a time, to the upper weight without setting the system in motion. The motion would be an accelerated one so long as the force was applied, it would become uniform when the force ceased to act; it would have a velocity proportionate to the force. In any case, after a time the descending weight would reach the ground, and for our point of view it is quite immaterial whether the time occupied by the movement were 5 minutes or 5,000 years, for be it observed, time does not enter into the definition of *work* as it does into that of "horse-power." Then by pushing the conceived conditions to their limits, we may see that without considering any question of conversion of motion into heat, the raised weight can, in theory at least, give back again the energy spent upon it.

only diffused throughout the universe in the form of radiant heat of low intensity. Yet it is lost for ever for useful purposes; for from this final form of diffused heat there is no known or conceivable process by which heat can be gathered up again.

Dr. Joule arranged paddles of brass or iron, so that they could turn freely in a circular box containing water or quicksilver. From the sides of the box partitions projected inwards, which contained openings that permitted the divided arms of the paddle to pass, and preventing the liquid from moving *en masse,* thus caused a churning action when the paddle was turned. Now, every one who has worked a rotatory churn knows that a considerable resistance is offered to this action; but every one does not know that under these circumstances the liquid becomes warmer. It was Dr. Joule's object to discover how much the temperature of his liquid was raised by a measured quantity of work. He used very delicate thermometers, and had to take a number of precautions which need not here be described; and he obtained the definite quantity of work by the descent of a known weight through a known distance, a cord attached to the weight being wound on a drum, which communicated motion to the paddle. The experiments were conducted with varying circumstances, to avoid chances of error, and were repeated very many times until uniform and consistent indications were always obtained. The result of the experiments showed that 772 units of work (foot-pounds) furnished heat which would raise the temperature of one pound of water from 32° to 33° F., which is the unit of heat. This number, 772, is a constant of the greatest importance in scientific and practical calculations, and is called "*the mechanical equivalent of heat.*" The amount of *work* it represents is sometimes called a "Joule," and is always represented in algebraical formulæ by "J." Mr. Joule's first paper appeared in 1843, and soon afterwards various branches of the subject of "The Equivalence and Persistence of Forces" were taken up by a number of able men, who have advanced its principles along various lines of inquiry. Among the most noted contributors to this question we find the names of Lord Kelvin, Helmholtz, James Thomson, Rankin, Clausius, Tait, Andrews, and Maxwell.

In the steam engine the case is the inverse of that presented by the above named experiment of Dr. Joule's. Here we have

heat producing work. Now, the quantity of steam which enters the cylinder of a steam engine may be found, and the temperature of the steam can be determined, and from these the amount of *heat* which passes into the cylinder per minute, say, can be calculated. A large portion of this heat is, in an ordinary engine, yielded up to the condensing water, and another part is lost by conduction and radiation from the cylinder, condenser, pipes, etc. But both these quantities can be estimated. When the amount is compared with that entering the cylinder in the steam, a difference is always found, which leaves a quantity of heat unaccounted for. When this quantity is compared with the *work* done by the engine in the same interval, it is always found that for every 772 units of work a unit of heat has disappeared from the cylinder. The numerical relation between work and heat which is established in these two cases has been tested in many quite different ways; and, within the limits of experimental errors, always with the same numerical result. But equally definite quantitative relations are known to exist among all the other forms of force; and the manner in which these are convertible into each other has already been indicated, although want of space prevents full illustration of this part of the subject. It may, however, be seen that each form of force can be mediately or immediately converted into mechanical effect, hence each is expressible in terms of work. That is to say, we can assign to a unit of electricity, for example, a number expressing the work which it would do if entirely converted into work; and the same number also expresses the work which would be required to produce the unit of electricity. An ounce of hydrogen in combining with eight ounces of oxygen produces a certain measurable quantity of heat. If that heat, say = H, were all converted into work, we now know that the work would = HJ. Hence we can express a definite chemical action in terms of *work*. The same is generally true of all physical forces, though in some cases, such as light, vital action, etc., the quantitative relations have not yet been definitely determined.

Since, then, all the forces with which we are acquainted are expressible (though the exact relations of some have yet to be discovered) in terms of work, it is found of great advantage to consider the power of doing work as the common measure of doing all these. Thus, if we define *energy* as that which does, or

that which is capable of doing, work, we have a term extremely convenient in the description of some aspects of our subject. Thus we can now speak of the *energies of nature,* instead of the forces. And all forces, active or passive, may be summed up in one word — *energy.* And, further, the great discovery of the conservation of forces under definite equivalents, may be summed up very briefly in this statement — THE AMOUNT OF ENERGY IN THE UNIVERSE IS CONSTANT. To make this statement clear requires that a distinction between two forms of every kind of energy be pointed out. To recur to the example before imagined: if you carry the pound weight to the top of the 100 foot building, it might lie there for a thousand years before it was made to give back the work you had performed upon it. That work has been, in a manner, *stored up* by the *position* you have given to your weight. Now, in taking up the weight, you expended energy — you really performed work: that is an instance of energy in operation, and may be termed "actual energy." In what form does the energy exist during the thousand years we may suppose your weight to lie at the top of the building? It is ready to yield up your work again at any moment it is permitted to descend, and it possesses therefore during the whole period a *potential energy* equal in amount to the *actual energy* you bestowed upon it. A similar distinction between actual and potential energy exists with regard to every form of force. If by any means you separate at atom of carbon from an atom of oxygen, you exert actual energy. The process is analogous to carrying up the weight. The atoms when separated possess *potential* energy,— they can rush together again, like the weight to the earth, and in doing so will give out the work which was expended on their separation. A parallel illustration might be drawn from electrical force.

A typical example of the storing up of energy is furnished by a crossbow. The moment a man begins to bend the bow he is doing work, because he pulls the string in opposition to the bow's resistance to a change in its form; and it is plain that the amount of energy thus expended is measurable. Suppose, now, the bow has been bent and the string caught in the notch, from which it is released by drawing the trigger when the discharge of the bow is desired. The bow may be retained for an indefinite period in the bent condition, and in this state it possesses, in

the form of *potential energy,* all the work which has been expended in bending it, and which it will, in fact, give out, in some way or other, whenever the trigger is drawn. To fix our ideas, let us suppose that to draw the string over the notch required a pull of fifty pounds over a space of six inches; that is equivalent to $50 \times \frac{1}{2} = 25$ units of work. Now let the bow be used to shoot an arrow weighing one-quarter pound vertically upwards. The height in feet to which the arrow will rise multiplied into its weight in pounds will be the work done upon it by the bow. Now, we say that experiment proves that in the case supposed the arrow would rise just 100 ft., so that the work done *by* the bow ($\frac{1}{4} \times 100 = 25$) would be precisely that done *upon it.* For the sake of simplicity, we keep this illustration free from the mention of interfering causes, which have to be considered and allowed for when the matter is put to the real test of quantitative experiment. The instance of the cross-bow brings into notice a highly instructive circumstance, which is this: the bow, which it may have taken the strength of a Hercules to bend, will shoot its bolt by the mere touch of a child on the trigger. In the same way, when a man fires a gun, he merely permits the *potential* energy contained in the charge to convert itself into *actual,* or *kinetic,* energy. The real source of the energy, in the case of the child discharging the cross-bow, is the muscular power of the man who drew it; the real source of the energy in exploding gunpowder is the separation of carbon atoms from oxygen atoms, and that has been done by the sun's rays, as truly as the string was pulled away from the bow by muscular power. If we turn our attention to nitro-glycerine or to nitro-cellulose, we can, by following the chemical actions giving rise to these substances, in like manner trace their energies to our great luminary. The unstable union by which oxygen and nitrogen atoms are locked up in the solid and liquid forms of nitro-cellulose and nitro-glycerine is also the work of the sun; for nitrogen acids, or rather nitrates, are produced naturally under certain electrical and other conditions of the atmosphere, which are due, directly or indirectly, to the sun's action; and they cannot be formed artificially, except by imitating the natural conditions, as by passing electric sparks through air, etc.

It will now be understood, as regards the wonderful relations between animal and vegetable life, which have already been

alluded to more than once, how the sun, by expending actual energy, separates atoms of carbon from atoms of oxygen in the leaves of plants, and confers upon these a position of advantage, i. e., potential energy; and how animals, absorbing the separated carbon in the form of food, and inhaling the separated oxygen in the air they breathe, cause the conversion of the potential into actual energy, which appears in the heat, movements, and vital functions of the animal body. In coal we have the energy which plants absorbed from the sun ages ago, stored up in a potential form. The carbon atoms are ready to rush into union with oxygen atoms, and convert their energy of position into the energies developed by chemical action, viz., heat, light, etc. Energy is thus constantly shifting its form from actual to potential, and *vice versâ,* and exhibiting itself under the various transformations of force, as when sun-force changes to chemical action, chemical action to heat, heat to electricity, etc. Energy is, indeed, the real modern PROTEUS — constantly assuming different shapes, difficult to grasp if not held in fetters; now taking on the form of a lion, now of a flame of fire, a whirlwind, a rushing stream. As sober, literal matter of fact we catch glimpses of energy under these very forms.

The greatest discovery of the age has, as already indicated, immediate and important practical bearings. The amount of thought which, even in the present day, is devoted by unscientific mechanics to the old problem of perpetual motion is far greater than is generally supposed. The principle of the conservation of energy shows that this is an impossibility; that the inventor who seeks to create force might just as well try to create matter; that the production of a perpetually moving self-sustaining machine is as far removed from human power as the bringing into existence of a new planet. In force, as in matter, the law is inexorable — *ex nihilo nihil fit.* Again, knowing the definite amount of energy obtainable from the combustion of a pound of coal, we can compare the amount we actually procure from it in our steam engines with this theoretical quantity as the limit towards which our improvements should bring us continually nearer, but which we can never exceed, or, indeed, even reach. The schemers of perpetual motion are not the only class of speculators who pursue objects which are incompatible with our principle. There are many who seek to accomplish desirable ends

by inadequate means: who, for example, are aiming perhaps to accomplish the reduction of ores by a quantity of fuel less than that mechanically equivalent to the work, or who conceive that by adding to coal some substance which itself is unchanged, an indefinitely greater amount of heat may be liberated by the combustion.

Enough has been said to show that the energies of animal life can be traced to the sun as their source. The sun builds up the plant, separating oxygen from carbon. The animal — directly or mediately by devouring other animals — takes the carbonaceous matter of the plant, and reunites it with oxygen. In the plant the sun winds up the spring which gives life to the animal mechanism; for the winding-up of a spring and the separation of the atoms having chemical affinities are alike instances of supplying potential energy. In the animal there is a running-down of the potential into actual energy. It is plain also that of the total energy radiated from the sun in every direction, the earth receives but a very small part ($\frac{1}{2300000000}$). By far the larger part is diffused into space, where, for all such purposes as those with which we are concerned, it is lost. The heat which the sun sends out in a year is calculated to be equal to that which would be produced by the combustion of a layer of coal 17 miles thick over the whole surface of the luminary. Is the sun, then, a flaming fire? By no means. Combustion is not possible at its temperature; and as we know the substances which enter into its composition are the same as those we find in the earth, we know that the chemical energies of such substances could not supply the sun's expenditure. Passing over as unsatisfactory an explanation which might occur to some minds — namely, that the sun was created hot at the beginning, and has so continued — there are two theories which attempt to account for the sun's heat. One is that of Meyer, who supposed the heat is due to the continual impact of meteorites drawn to the sun by its gravity; and the other is that of Helmholtz, who attributes the heat to the continual condensation of the substance of the sun. Helmholtz calculates that a shrinking of the sun's diameter by only $\frac{1}{10000}$th of its present amount, would supply heat to last for two thousand years; while the condensation of the substance of the sun to the density of the earth would cover the sun's expenditure for 17,000,000 of years. There is great probability that

both theories may be correct, and that the cause of the sun's heat may be considered as due in general terms to aggregation of matter, by which the original potential energy of position is converted into the actual energy of heat and light. Now, however immense may be our planetary system, the sun being continually throwing off this energy into space, there must come a time when the supplies of meteorites will fail, and when the great globe of the sun will have shrunk to its smallest dimensions. We see, then, that heat and light are produced by the aggregation of matter; the heat and light are radiated into space; the small fraction intercepted by our globe is the source of almost every movement — the original stuff, so to speak, out of which all terrestrial forces are made. The sun produces the winds, the thunderstorms, the electric currents of the Aurora, the phenomena of terrestrial magnetism, and is the source of vegetable and animal life. The waves, the rains, the mountain torrents, the flowing rivers, are the work of the sun's emanations.

In the illustration of the energy expended on raising a weight afterwards dropped, we traced that energy into the final form of heat of a low temperature radiated into space. It would be easy to show that all energy ultimately takes the same form. Now, although it is easy to convert work into heat, there is no conceivable process by which uniformly-diffused heat can again be made to do any kind of work. The case may be compared to water, which in moving down from a higher to a lower level may be made to perform any variety of work. But when all the water has passed down from the higher level to the lower, it can no longer do any work. Whenever work is done by the agency of heat, there is always a passing from a higher temperature to a lower — a transference of heat from a hotter body to a colder. If the condenser of the steam engine had the same temperature as the steam, the machine would not work. Not only do all the energies in operation on the face of the earth continually run down into the form of radiant heat sent off by the earth into space; but our sun's energy, and that of the suns of other systems, are also continually passing off into space; and the final effect must be a uniform diffusion of heat in a universe in which none of the varied forms of energy we now behold in operation will be possible, because all will have run down to the same dead

level of uniformly-diffused heat. This startling corollary from the principle of the conservation of energy has been worked out by Lord Kelvin under the title of "The Dissipation of Energy." It leads us to contemplate a state of things in which all light and life will have passed away from the universe — a condition which the poet's terrible dream of darkness, "which was not all a dream," seems to shadow forth —

> "The bright sun was extinguished, and the stars
> Did wander darkling in the eternal space,
> Rayless and pathless; and the icy earth
> Swung blind and blackening in the moonless air.
> * * * * * *
> The world was void,
> The populous and the powerful was a lump,
> Seasonless, herbless, treeless, manless, lifeless —
> A lump of death — a chaos of hard clay.
> The rivers, lakes, and ocean all stood still,
> And nothing stirred within their silent depths.
> * * * * * *
> The waves were dead; the tides were in their grave,
> The Moon, their mistress, had expired before;
> The winds were withered in the stagnant air,
> And the clouds perished; Darkness had no need
> Of aid from them — She was the Universe."

The doctrine of this persistence and dissipation of energy completely harmonizes with the grand speculation termed the "nebular hypothesis," which regards the universe as having originally consisted of uniformly diffused matter, which, being endowed with the power of gravitation, aggregated round certain centers. This process is still going on; and, according to modern speculations, light and life and motion are but manifestations of this primæval potential energy being converted into actual energy, and degrading ultimately into the form of universally-diffused heat. To quote the closing sentences of the eloquent passage in which Professor Tyndall concludes the work mentioned above, "To nature nothing can be added, from nature nothing can be taken away; the sum of her energies is constant, and the utmost man can do in the pursuit of physical truth, or in the applications of physical knowledge, is to shift the constituents of the never-varying total. The law of conservation rigidly excludes both creation and annihilation. Waves may change to ripples,

and ripples to waves; magnitude may be substituted for number, and number for magnitude; asteroids may aggregate to suns, suns may resolve themselves into floræ and faunæ, and floræ and faunæ melt in air: the flux of power is eternally the same. It rolls in music through the ages, and all terrestrial energy — the manifestations of life as well as the display of phenomena — are but the modulations of its rhythm."

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